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# Assessment of Shallow Water Influence Minesweeping System (SWIMS) implementation utilizing CH-60

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Monterey, California: Naval Postgraduate School

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# NAVAL POSTGRADUATE SCHOOL
## Monterey, California

# THESIS

**ASSESSMENT OF SHALLOW WATER INFLUENCE MINESWEEPING SYSTEM (SWIMS) IMPLEMENTATION UTILIZING CH-60**

by

James K. Edwards

December 1999

Thesis Advisor: Kneale T. Marshall
Second Reader: George W. Conner

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The purpose of this study is to analyze the feasibility of, and the trade-off possibilities for, different types of AMCM operations using the CH-60 and SWIMS system. Given the planned limited capabilities of the CH-60/SWIMS system relative to the MH-53E/MK-106 system, we explore methods for determining; (i) how to operate CH-60/SWIMS using proposed new employment methods, (ii) how many CH-60's will be required to clear a specified MDA, and (iii) how to minimize the operational impact to the ships involved.

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# ASSESSMENT OF SHALLOW WATER INFLUENCE MINESWEEPING SYSTEM (SWIMS) IMPLEMENTATION UTILIZING CH-60


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## ABSTRACT

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## DISCLAIMER

The reader is cautioned that computer programs developed in this research may not have been exercised for all cases of interest. While every effort has been made, within the time available, to ensure that the programs are free of computational and logic errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the planner.

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## LIST OF SYMBOLS, ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| AIMD | Aviation Intermediate Maintenance Department |
| AMCM | Airborne Mine Countermeasures Mission |
| AOA | Analysis Of Alternatives |
| ARG | Amphibious Readiness Group |
| CG | guided missile cruiser |
| CH-60 | multi-purpose cargo version of the Navy's Sikorsky H-60 helicopter |
| CVBG | Carrier Battle Group |
| CVN | nuclear-powered aircraft carrier |
| DD/DDG | guided missile destroyer |
| ETOTITL | Expected Time On Top In The Lap, actual sweep time |
| JHU/APL | Johns Hopkins University, Applied Physics Laboratory |
| JWAD/JMA | Joint Warfare Analysis Department, Joint Mission Analysis group at Johns Hopkins University, Applied Physics Laboratory |
| LAMPS | Light Airborne Multi-purpose System |
| LHD | multi-purpose amphibious assault ship |
| LPD/LSD | amphibious assault ships |
| MDA | Mine Danger Area |
| MH-53 | current helicopter used for AMCM by the Navy |
| MK-106 | current airborne influence sweep system used by the Navy for AMCM |
| OIC | Officer-In-Charge |
| ORD | Operational Readiness Document |
| PUK | Pack-Up-Kit, basic spare parts for the helicopter |
| SH-60 | surface warfare/under sea warfare version of the Navy's Sikorsky H-60 helicopter |
| SWIMS | Shallow Water Influence Mine Sweeping system |

| | |
|---|---|
| hr | hour |
| kts | nautical miles per hour |
| kVa | thousand volts per ampere |
| lbm | pounds mass |
| lbf | pounds force |
| min | minute |
| nm | nautical miles |
| sw | sweep width |
| yds | yards |

## EXECUTIVE SUMMARY

The Sikorsky H-60 airframe is planned to be the only rotary-wing aircraft in the Navy's inventory through 2015. The CH-60 variant will support the Airborne Mine Countermeasures (AMCM) mission, replacing the current MH-53E and it's MK-106 towed influence system. The CH-60's towing capacity will be significantly less than the MH-53E, so new equipment, designated the Shallow Water Influence Mine Sweeping (SWIMS) system. Capability of SWIMS is expected to be significantly less than that of the MK-106 system. Smaller size and aircraft commonality will enable SWIMS to deploy on most surface combatants, providing forward presence and reducing employment time of an AMCM suite into a Mine Danger Area (MDA).

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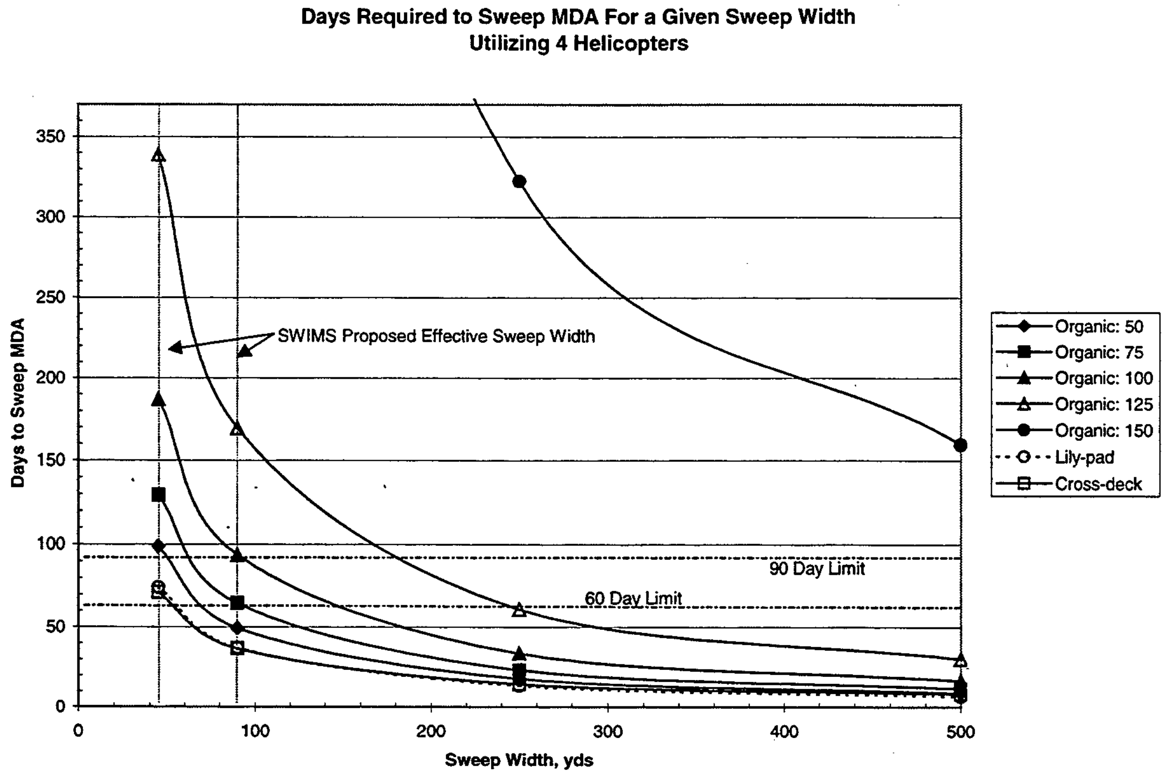
The combination of reduced effective sweep width and a shorter flight-time per mission length, approximately 3.5 hours, leaves the operational commander few feasible methods for successful AMCM employment. The figure below provides a representation of the tactical problems introduced by the CH-60 and SWIMS in an AMCM role.




Tactical Implications of Proposed SWIMS Sweep Width. 4 helicopters available for organic, lily-pad, and cross deck operations. Organic transit distances are indicated in the legend, (eg. Organic:50 refers to organic operations at 50 nm). Transit distances for lily-pad and cross-deck operations are 15 nm and 5 nm respectively.

The figure above shows that using SWIMS to sweep a 180 nm strait would take approximately 180 days using four organic CH-60 helicopters. The time-to-sweep of 180 days is also based on the mother ship maintaining a safe standoff distance of 125 nm.

Our conclusions suggest the following: (i) organic AMCM operations are infeasible for many expected operational situations due to short mission duration and high transit times. (ii) lily-pad and cross-deck operations will be required to sweep large MDA's to ensure safe positioning of the mother ship. (iii) The CH-60 is currently not

capable of cross-deck operations due to the lack of a RAST probe in order to mount the tow equipment for SWIMS.

Exploration of the model illustrates the importance of small-deck operations to AMCM operations of the future. SWIMS is not expected to have the effective sweep width to allow one or two helicopters to sweep a significantly sized MDA, (greater than 100 nm of swept channel). Sweeping a 180 nm channel for a ship count of 10 would require 3-5 SWIMS-equipped helicopters to operate from small-deck combatants for a period of 60 days. Relying solely on lily-pad operations would require the mother ship to stay within 150 nm of the small-deck ships. Allowing the use of cross-deck operations would require modifications not yet planned for the CH-60 to allow for safe storage of the helicopter, or a method of moving the helicopters in and out of the small-deck ship's hangar. In addition to these, developing greater effective sweep widths for SWIMS will allow more employment diversity with shorter sweep times.

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# I. INTRODUCTION

The Sikorsky H-60 airframe is planned to be the only rotary-wing aircraft in the Navy's inventory through 2015. [Ref. 1] Mission-specific variants of this airframe include the CH-60, which will be required to support the Airborne Mine Countermeasures (AMCM) mission. The towing capacity of the CH-60 is significantly less than that of the current AMCM aircraft, the MH-53E. Due to this reduced towing capacity, a new equipment suite must be designed to replace the current towed influence AMCM system, the MK106 AMCM suite. Up to four CH-60 aircraft are expected to deploy either as a squadron or as a detachment with Nuclear-powered Aircraft Carriers (CVN) and amphibious assault class ships which include Multi-purpose Amphibious Assault ships (LHD) and Dock Landing Ships (LSD).

This new AMCM system has been designated as the Shallow Water Influence Mine Sweeping (SWIMS) system. SWIMS is the only replacement to the MK-106 currently being considered by the United States Navy. The capability of SWIMS is expected to be less than that of the current MK-106 system and will require new tactics, doctrine, and employment techniques if future AMCM missions are to be successful.

The smaller size of the towed-body and aircraft commonality will enable SWIMS to deploy on most surface combatants. This will enable a forward presence, reducing the employment time of an AMCM suite into a known or suspected Mine Danger Area (MDA) compared to the current MH-53 towed MK-106 suite or the MCM-1 class minesweeper. Forward presence and reduced employment time are essential to providing

a rapid response. The SWIMS gear will require extended on-station time to counter the future mine threat, but should be readily accessible to the operational commander. Three methods of AMCM employment are envisioned: organic operations from the "mother" ship, lily-pad operations utilizing a surface combatant as a refueling platform near the MDA, and cross-deck operations utilizing a surface combatant as a forward operating base near the MDA. Any combination of these three methods could be employed to clear one or more MDA.

Chapter II contains a discussion of feasible future AMCM tactics and operations made feasible by the use of the smaller CH-60 and its planned towed influence system SWIMS. Although the reduced size of the airframe and its towed AMCM system will allow for forward presence of this new equipment, making airborne mine sweeping theoretically more efficient, significant operational problems arise when details of tactics and operations are studied. The concepts of lily-pad and cross-deck AMCM operations compared to organic operations are defined and described, along with the logistics problems that accompany these types of operations.

Chapter III contains an operational spreadsheet model that determines the time to sweep a given MDA using various operational combinations of CH-60's and their deployment. Chapter IV contains numerical results based on typical MDA operations. These results show that cross-deck and/or lily-pad operations will be necessary given the expected performance characteristics of SWIMS. Appendices C and D contain more detailed numerical results for the model exploration in Chapter IV.

Chapter V contains a modified version of the calculations in Chapter III that is used to calculate the number of helicopters required to sweep a given MDA in specified length of time. Sample calculations and results for the modified model are contained in Appendix E.

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# II. BACKGROUND

The MCM Force-21 Study Final Results states that "The current mine countermeasures (MCM) force is not well postured to facilitate the naval operational concepts envisioned for forward-deployed naval forces in *Forward... From the Sea*". [Ref. 1] With the MH-53E and, correspondingly, the MK-106 suite being retired from service within the next few years, the Navy will possess the CH-60 and SWIMS as the sole AMCM influence sweep platform. Planning for reduced on-station time and reduced sweep capabilities only addresses part of the problem. The CH-60 will be required to perform a variety of mission tasks in addition to AMCM while deployed with a Carrier Battle Group (CVBG) or an Amphibious Readiness Group (ARG). To utilize the full potential of the CH-60 in its multi-mission role, AMCM must be carefully planned to cause a minimal operational impact to the battle force.

## A. SWIMS EMPLOYMENT METHODS

Several problems need to be addressed when considering the employment of SWIMS. Ideally, all AMCM missions would stage from the mother ship, allowing most mechanical problems and refueling issues and corresponding tasks to be handled with relative ease. Current naval doctrine may prevent the "high-value" units from proceeding to a point close enough to the MDA to reasonably conduct organic AMCM operations. If so, this will require the use of a surface combatant such as a cruiser or destroyer, as either a refueling platform or as an extended base of operations. By utilizing the surface

combatant in either the lily-pad or cross-deck role, MDA's may be effectively neutralized while the CVBG or ARG remains in safer waters able to perform other operations such as over-land air strikes or troop insertion.

### 1. Organic, Lily-pad, and Cross-deck AMCM Operations

Organic AMCM operations involve flight operations directly from the large-deck amphibious assault ship or aircraft carrier the AMCM detachment is embarked in. The effective radius for AMCM operations will be 150 nm or less and the organic ship would handle all refueling and maintenance issues. lily-pad operations involve flight operations directly from the large-deck ship as well. The difference between organic and lily-pad operations is that the helicopter will be refueled by a small-deck ship that is closer to the MDA than the host organic-ship or "*mother*" ship. The AMCM helicopter would then return to the mother ship upon mission completion or at the end of the day. cross-deck operations involve temporary transfer of the helicopter, equipment, and crews, both maintenance and flight crews, from the mother ship to a small-deck combatant for the duration of the AMCM mission. This will require the AMCM detachment to have a dedicated helicopter hangar for extended use and a partial Pack-Up-Kit (PUK) pre-staged on the small-deck combatant. Appendix A contains a partial list of items to be considered for a PUK when a CH-60 detachment is going to cross-deck to a surface combatant without an Aviation Intermediate Maintenance Department (AIMD) on board.

There are several reasons why any one of these employment methods might be chosen over the others. Organic AMCM would most likely place the "high-value" unit or

capital ship of the line too close to the MDA and coastal defenses. Additionally, the primary mission for these capital ships is not AMCM; the AMCM mission is only conducted when an MDA is encountered and then the mission will only last for as long as necessary to neutralize a lane through the MDA. This would allow the capital ship again to pursue its main mission of power projection ashore.

Lily-pad operations would allow for multiple refueling operations from a small-deck ship closer to the MDA than the capital ship, require less transit time and allow for greater on-station times. This type of operation would allow the helicopter to conduct extended AMCM operations with SWIMS at a distance of 150 nm or less and would allow the same level of mechanical repair as organic AMCM operations. This type of operations is not only restricted by distance, but also by allowable transit time to and from the MDA. Also, if maintenance personnel or system operators need to accompany the SWIMS team, the entire flight must be conducted during daylight hours. No over-water passenger transfers are allowed at night.

Cross-deck operations would allow almost all of the available flight time to be devoted directly to neutralizing the MDA, once the logistical portion of the cross-deck has been completed. The transfer of equipment and personnel from the "mother" ship to the cross-deck ship could take nearly a day and, as long as passenger transfers were involved, would need to be performed during daylight hours. Once the AMCM mission was underway, the surface combatant would be able to exceed the 150 nm ship-to-ship over-water flight restriction, but would have to handle any maintenance problems that arose.

Cross-deck AMCM operations would also be restricted by any other mission requirement on the cross-deck ship. It is assumed that the cross-deck ship would also have an organic Light Airborne Multipurpose System (LAMPS) MK III SH-60B detachment embarked. LAMPS MKIII helicopters are multi-mission capable aircraft, which perform Surface Warfare (SUW), Undersea Warfare (USW), Maritime Interdiction Operations (MIO), and several similar missions on a daily basis while operating from small-deck combatants. Only one of the two aircraft, the SH-60 or the CH-60, could be airborne at any given time unless there were alternate landing platforms available. Therefore, it is conceivable that a LAMPS MK III mission could take precedence over the AMCM mission, extending the time required to effectively clear a safe lane through an MDA.

During both cross-deck and lily-pad operations, it is imperative that the AMCM helicopters operate as a self-sufficient detachment. Ship personnel are already over-tasked while performing normal shipboard duties due to insufficient manning levels and can not take on any additional tasks brought about by the addition of the AMCM mission. Future ship design studies are looking to further reduce the number of personnel assigned to a ship, this will require a self-sufficient AMCM detachment for any cross-deck AMCM operations. Due to the similarities in airframes, the embarked MK III detachment may be able to provide basic maintenance assistance to the AMCM detachment but ship personnel will only be available for flight quarters and other normal shipboard duties.

## B. PURPOSE AND RATIONALE

The purpose of this study is to analyze the time and equipment requirements for organic, lily-pad, and cross-deck AMCM operations utilizing the CH-60 and SWIMS. In addition, we explore a method for determining the number of aircraft required to clear a specified MDA, and staging those aircraft for a given flotilla compliment in order to reduce the operational impact to the ships involved.

Figure 1 provides an illustration of the three employment techniques: organic, lily-pad and cross-deck operations. Once the cross-deck helicopter has completed the requisite logistics transfer, the cross-deck CG/DD/DDG can maneuver outside the 150 nm ship-to-ship over-water restriction. A lily-pad CG/DD/DDG must stay inside the 150 nm restriction so the helicopter can land on the CVBG/ARG at the end of a day's AMCM operations. organic AMCM operations would have take place 150 nm or less from the MDA.

Because the SWIMS gear and the CH-60 are less capable than their current counterparts in the role of influence sweep AMCM, new methods and tactics for MDA neutralization will need to be developed. We propose to provide a model designed to determine the minimum number of aircraft that must be employed to meet the operational requirement (specified MDA clearance), or provide the minimum amount of time required to sweep an MDA given a specified number of aircraft. These recommendations should assist tactical planners in developing SWIMS-specific tactics using realistic criteria.

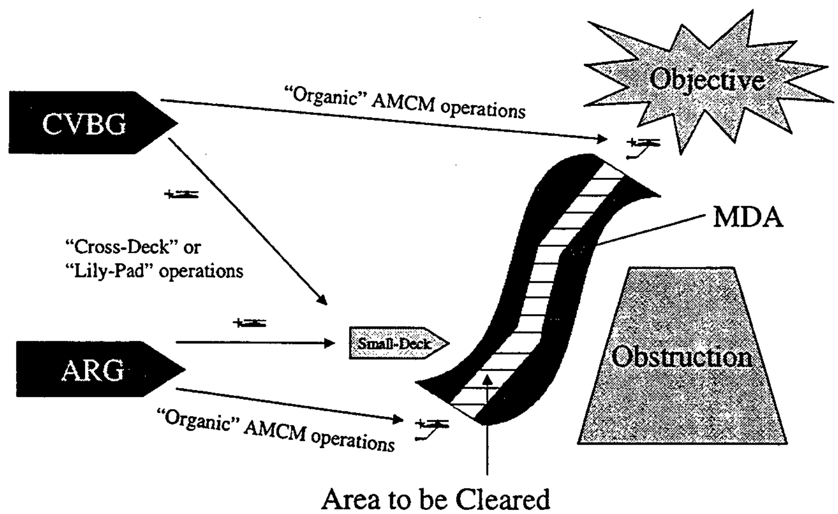


**Figure 1: Operational Realm. Provides a condensed graphic representation of the AMCM scenario. Organic operations from the CVBG or ARG would typically have transit distances greater than 100 nm to provide a buffer zone for the high value ship. Lily-pad and cross-deck operations would typically be conducted using transit distances of 5 to 15 nm.**

## C. RESEARCH APPROACH

The Operational Requirements Document (ORD) for the SWIMS Program provides only general guidance as to how SWIMS is to be employed. It focuses on the current systems and how SWIMS must meet the future mine threat. The lack of tactical guidance is borne out in two briefs prepared by John Benedict, Jr. of Johns Hopkins University, Applied Physics Laboratory (JHU/APL) entitled "SWIMS Analysis of Alternatives (AOA) Study Plan Perspectives (Brief to PMS210 & N81 Co-Chairs)", [Ref. 2] and "Key Issue Areas Addressed in MCM Force-21 Study (During Seminar Exercise Process)." [Ref. 3] These briefs discuss the requirements for using the CH-60 for towing

SWIMS and the requirements for conducting the SWIMS AMCM mission from large-deck CVN and LHD/LSD ships as well as small-deck surface combatants such as CG, DD, and DDG. The briefs do not discuss the logistics required for operating SWIMS from small-deck ships or any specifics of SWIMS operation.

From the Benedict documents, the following have not been determined: (i) the location and type of tail-wheel that the CH-60 would use, and (ii) whether or not the aircraft would fit into the hangar of a surface combatant. The Navy has accepted the CH-60 procurement program. It is currently funded and in the process of producing aircraft. The tail of the CH-60 will fold at the same location as that of the current maritime versions of the H-60 airframe. The B, F and R variants would allow the CH-60 to operate for extended periods from small-deck surface combatants. The tail-wheel will be located forward of the tail-fold hinge allowing the aircraft to be maneuvered on the flight deck and in the hangar area while in the folded position. [Ref. 4] The method for maneuvering the aircraft on small-decked ships must still be determined. The decks themselves are too small to allow the use of a tow tractor, (the method for maneuvering aircraft on CVN and LHD class ships) and the aircraft will not have a Recovery Assist Straightening and Traverse (RAST) system to allow it to be maneuvered on deck like the SH-60B/R variants. This should create some concern for the CH-60 Program Office because maneuvering a 23,000 pound aircraft on a pitching and rolling flight deck by hand is a dangerous operation at best.

Operating limits and Mean Time Between Failure (MTBF) numbers for rotating components of the CH-60 were supplied by the aircraft manufacturer, Sikorsky Aircraft,

Inc. These numbers were originally intended to be applied to the model to ensure no aircraft component high-time limits are encountered while an aircraft is supposed to be flying. During model exploration, it was determined that the expected low-effective sweep width values for the SWIMS gear would limit AMCM employment methods. MTBF times for the rotating components could be added once the model can be developed further. MTBF numbers for the SWIMS gear are not yet available.

The operating limitations for the SWIMS gear are restricted by the design of the CH-60. The towed body itself must not weigh over 1000 lbm, cannot consume more than 15kVa and must require no more than 6000 lbf of constant tow tension during towing operations. [Ref. 5] The operational capabilities of the SWIMS gear are being generated with the aid of the Total Mine Simulation System (TMSS). This system will be able to determine the ability of the SWIMS gear to neutralize specific mine types when operating in various open-water and littoral scenarios. The data obtained from Sikorsky and TMSS will then be adapted to fit the conceptual model.

# III. CONCEPTUAL MODEL

This chapter starts with a description and discussion of the necessary details of AMCM operations and constraints. A spreadsheet model that is then developed calculates the time to sweep a given MDA assuming a given operational situation. It is assumed throughout this thesis that air superiority is present during all AMCM operations.

There are three scenarios being considered for analysis: organic, lily-pad and cross-deck operations. Of those three, cross-deck operations appear to be the most complex due to the logistics transfers required, and will be discussed first. A typical cross-deck mission will begin with the logistics transfer of materiel, parts and personnel. The logistics phase will be restricted to the hours of daylight as long as personnel are being transferred, otherwise parts and materiel can be transferred at night. The time required for the logistics phase is very dependant on the distance between the mother ship and the cross-deck ship, but it is anticipated that the phase will consist of two parts and materiel transfer evolutions, one personnel, parts and materiel transfer evolution and one personnel transfer evolution.

The helicopter will be loaded for the first transfer and depart for the cross-deck ship. Upon reaching the vicinity of the cross-deck ship the helicopter will begin the recovery sequence which typically takes ten minutes if the helicopter is expected at the cross-deck ship. An additional fifteen minutes should be planned for if the helicopter is not expected. After landing, the helicopter will be unloaded and refueled, this should take approximately 10-15 minutes depending on the amount of cargo that requires unloading.

Unless the mother ship and the cross-deck are within visual range of each other, the helicopter will always refuel before going back to the large-deck ship. This refueling is done in order to be prepared for any unscheduled landing delays encountered when arriving at the carrier or amphibious ship. Helicopters are typically given the lowest landing priority at these ships because of their relatively low fuel consumption and lower cost of replacement when compared to high performance jet aircraft. The landing sequence at the mother ship should be expected to take approximately twenty minutes, including delays.

After arrival back at the mother ship, the helicopter will re-load for the next logistics mission and possibly refuel. If the mother ship is in the process of launching and recovering aircraft, an extended delay should be expected while waiting for fuel. The mother ship typically will not refuel aircraft on the flight deck during launch and recovery operations. Delays of this kind can be avoided by proper scheduling, so a loading and refueling delay of thirty minutes should be expected.

Once the logistics phase is completed, the helicopter must be configured for the AMCM mission. Helicopter mission conversion from cargo/logistics to AMCM should take approximately 45 minutes. The exact time will not be known until the actual equipment is manufactured and tested. Due to the amount of time and manpower required during the logistics phase, mission conversion will probably take place at night, in between mission days. Inclusion of mission conversion time will also be dependent on the distance between the mother ship and the cross-deck ship.

Once the logistics phase is complete and the helicopter is configured for the AMCM mission, the three methods of employment all happen in a similar manner. It is still undetermined whether or not an equipment operator for the SWIMS gear will be required on the ship during AMCM operations. If an operator is required on board the ship, lily-pad operations will require a small logistics transfer. It is currently assumed that the helicopter crew will handle all SWIMS gear operation while in flight.

After take-off, the helicopter will then proceed to the vicinity of the MDA and the area to be cleared to deploy the SWIMS gear. SWIMS deployment and stabilization will take approximately 10 minutes. Once the gear is stabilized, sweeping will begin along a 1,000 yard channel in a stepping manner at a speed of 22 knots. Turning the helicopter to begin a new sweep should take approximately 3 minutes in order to keep the SWIMS gear stable. The CH-60 will be able to fly continuously for 3.5 hours from take-off to landing. Ten minutes should be allowed for recovery of the SWIMS gear before the helicopter can begin the transit back to its refueling platform. Ten minutes for recovery should be allowed if the helicopter is going back to a small-deck ship and twenty minutes if the recovery ship is a CVN or LHD class ship. Once the helicopter has been refueled, the crew can re-launch and continue the AMCM mission until sunset or the mission is complete.

After careful consideration and problem space exploration, it was felt that this particular problem involves a number of different and conflicting measures of effectiveness (MOE's). We model the scenario using spreadsheet software to combine all of the required data elements and recommend an employment technique based on set

transit distances, MDA geometries and available SWIMS assets. In addition to providing an estimated time required to clear a specified area with a given number assets, the model is useful in helping determine the number of assets required to clear an area in a specified amount of time. Additionally, a determination will be made as to which method of SWIMS employment would be the most beneficial to the group commander based on distance from the mother ship to the MDA and the number of small-deck ships available for AMCM tasking.

The model considers the following data elements in the formulation of the time required to sweep a given MDA for a given ship count as an aid to the decision maker:

## A. DATA INPUT

| | |
|---|---|
| channel_w | channel width, nm. Width of channel to be swept through MDA. |
| area_len | area length, nm. Length of channel to be swept through MDA. |
| section_len | section length, nm. Length of each sweep section. Typically, not more than 5 nm. |
| ship_count | highest ship count expected in MDA. |
| sweep_vel | sweep velocity, kts. Expected to be 22 kts for SWIMS. |
| depth | number of depths to sweep, 1 for this study |
| nav_error | navigational error, yds. Combined error effect of equipment capability and the true track of vehicle being towed, typically 25 yds. |
| time_to_turn | turn time, min. Time required to turn the tow vehicle for the next sweep, typically 3 min. |
| mcm_density | MCM density, number of effective coverages for a given sweep |
| helo_avail | helicopters available. Number of helicopters available for the AMCM mission. |
| trans_dist | transit distance, nm. Distance from the AMCM platform ship to the MDA. |
| trans_vel | transit velocity, kts. Transit airspeed for the AMCM helicopter, typically between 90 and 120 kts. |
| refuel_time | refuel time, min. Time required to refuel an AMCM helicopter, typically 10 minutes from a small-deck combatants and 12 minutes from a large-deck carrier or amphibious assault ship. |
| stream_time | stream/recovery time, min. Time required to stream or recover the |

| | |
|---|---|
| | SWIMS gear, typically 15 minutes. |
| t_around_time | turn around time, min. Time required to perform flight quarters in order to launch or recover the AMCM helicopter. |
| mission_time | mission time, hr. Flight time available for a single sortie, from launch to recovery, typically 3.5 hours. |
| day_time | day time, hr. Hours of daylight available for the AMCM mission per day. |
| log_xfer_days | estimated number of days required to complete a one-way logistics transfer. This includes supplies, parts, equipment, and personnel. |

## B. DATA OUTPUT

| | |
|---|---|
| num_sections | number of sections. Number of sections the swept channel will be divided into. |
| eff_sweep | effective sweep width, yds. Effective width of a "cookie-cutter" sensor representing the SWIMS system. Random number generated from the combination of a triangular (10, 100, 100) distribution and an exponential (175) distribution. |
| mcm_eff | MCM efficiency. Measure of improvement obtained by performing AMCM sweeps in parallel tracks. |
| clear_lvl | clearance level. Clearance level for a ship count one influence sweep. |
| turns | turns per section. Number turns required for each section, based on effective sweep width. |
| sweep_prob | sweep probability. Probability of mine actuation for a given sweep within the mines detection range. Assumed to be one because of the use of a "cookie-cutter" sensor. |
| track_sep | track separation, yds. Effective spacing between sweeps. |
| missions_per_day | missions per day. Number of missions or sorties available for a given day. Based on amount daylight, mission time, and number of helicopters available. |
| eff_mission_time | effective mission time, hr. Amount of flight time available per sortie to devote to AMCM sweeping. |
| Etotitl_sec | effective time on task in the lap per section, hr. Time required to sweep a given section including turn time, based on a given effective sweep width and ship count. |
| Etotitl | effective time on task in the lap, hr. Time required to sweep a given MDA. The summation of all Etotitl times per section. |
| num_missions_req | number of missions required. Total number of missions or sorties required to sweep a given MDA. |
| days_to_clear | days to clear. Number days required to clear a given MDA, based on Etotitl, the number of missions required, and the number of helicopters available. |

## C. TIME-TO-SWEEP CALCULATIONS

Table 1 demonstrates the results of calculating the "time-to-sweep" a given area based on operator entered data. Effective sweep width can either be entered by the user or generated as a random number.

| INPUT | | OUTPUT | |
|---|---|---|---|
| channel_w, (nm) | 0.50 | num_sections | 37 |
| area_len, (nm) | 180.20 | eff_sweep, (yds) | 74.78 |
| section_len, (nm) | 5.00 | mcm_eff | 1.7181 |
| ship_count | 10 | clear | 0.8206 |
| sweep_vel, (kts) | 22 | turns | 14 |
| depth | 1 | sweep_prob | 1 |
| nav_error, (yds) | 25 | track_sep, (yds) | 74.7791 |
| time_to_turn, (min) | 3.0 | missions_per_day | 12 |
| mcm_density | 1 | eff_miss_time, (hr) | 1.9242 |
| helo_avail | 4 | Etotitl_sec, (hr) | 37.0789 |
| trans_dist, (nm) | 50.0 | Etotitl, (hr) | 1371.9191 |
| trans_vel, (kts) | 110 | num_missions_req | 712.9816 |
| refuel_time, (min) | 12.0 | days_to_clear | 59.4151 |
| stream_time, (min) | 15.0 | | |
| t_around_time, (min) | 10.0 | | |
| mission_time, (hr) | 3.5 | | |
| day_time, (hr) | 12.0 | | |
| log_xfer_days, (days) | 0.0 | | |

**Table 1. Sample Time-To-Sweep Inputs and Calculation Results. Calculations for Data Set 1, organic AMCM transit distances from 50 nm to 150 nm, 15 nm lily-pad transit distance, 5 nm cross-deck transit distance, and 1 day for one-way logistics transfer.**

Equation 1 determines the number of sections the area will need to be divided into for sweeping. If the section length does not divide evenly into the area length, the number of sections is rounded up to the next integer.

$$\text{num\_sections} = \left\lceil \frac{\text{area\_len}, (nm)}{\text{section\_len}, (nm)} \right\rceil \tag{1}$$

Equation 2 calculates a random number for effective sweep width. The random number generation is available to the user due to the fact that the actual SWIMS gear has yet to be built and tested. The user can also specify an effective sweep width for use in the calculations if desired. It was felt that this method of generating an effective sweep width provided a fair representation of the sweep width values being produced by the test modules at Johns Hopkins University Applied Physics Laboratory, Joint Warfare Analysis Department, Joint Mission Analysis Group (JWAD/JMA) for the SWIMS gear. Additionally, effective sweep width is a complex function of several environmental and equipment factors which are beyond the scope of this thesis. If the user does not feel prepared to provide a specified sweep width, this alternate method is provided.

$$
\begin{aligned}
&\textit{generate}: X = [\text{uniform}(0,1)]; \qquad\qquad (2)\\
&\qquad \textit{if}\,(X \cdot \leq 0.4)\\
&\qquad\qquad \textit{generate}: Y = [\text{triangular}(10,100,100)];\\
&\qquad \textit{else}\\
&\qquad\qquad \textit{generate}: Y = [\text{exponential}(175)];\\
&\text{eff\_sweep} = Y.
\end{aligned}
$$

Figure 2 represents a distribution of 5000 sample generations from Equation 2.

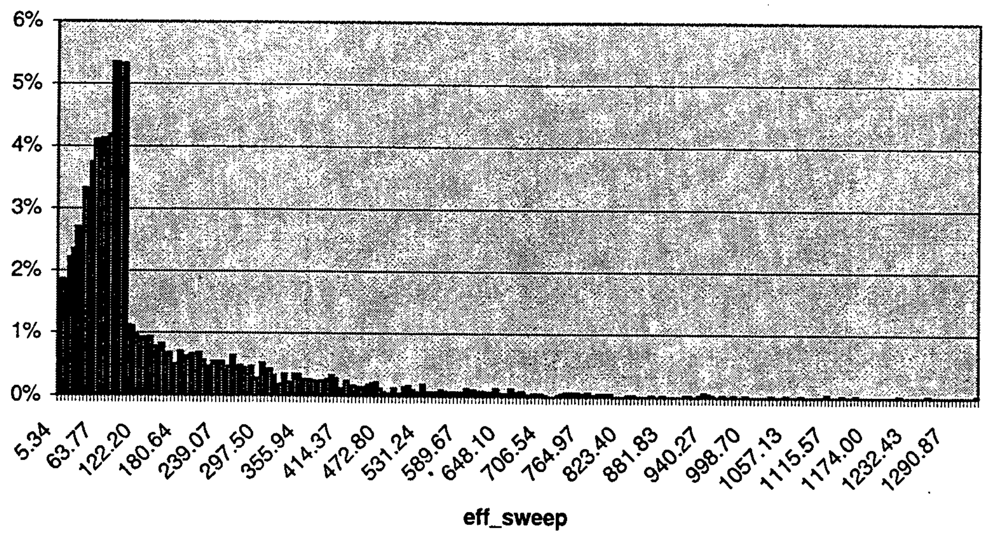


**Figure 2: Effective Sweep Distribution. Representation of 5000 random sweep width generations from Equation 2.**

Equation 3 calculates the MCM efficiency. MCM efficiency is a measure of how much improvement is obtained by sweeping in parallel tracks when compared to the case where all tracks are randomly placed. For all randomly placed tracks, MCM efficiency would be 1. MCM efficiency is dependent on the probability that an encountered mine will be swept effectively when within range. Equation 3 and subsequent equations used were obtained from JWAD/JMA and support the U.S. Navy's AMCM operational procedures. An assumption for this model is that the sweep probability is based on a cookie-cutter sensor with an effectiveness probability of one. This assumption allows MCM efficiency to be calculated log-linearly by Equation 3.

$$\text{mcm\_eff} = \exp\left[0.0007 + 0.1807 * \left(\frac{\text{eff\_sweep}, (yds)}{\text{nav\_error}, (yds)}\right)\right]. \tag{3}$$

Equation 4 calculates the clearance level for a mechanical sweep for a ship count of one, for example, a clearance level of 0.85 would indicate that 85 % of ship count one mines will have been successfully swept by a single sweep of the MDA. Although the model allows multiple ship counts, the calculation of clearance level based on a ship count of one is sufficient to allow further interpretation by the user. The actual clearance level for multiple ship counts will not be as high a value as the single ship count level, but the calculation of that value is beyond the scope of this thesis.

$$\text{clear\_lvl} = 1 - \exp(-\text{mcm\_density} * \text{mcm\_eff}). \tag{4}$$

Equation 5 calculates the number of turns required per section. The number turns per section must be an integer therefore, an integer value is obtained by a manner similar to that in equation 1.

$$\text{turns} = \left\lceil \left( \frac{\text{channel\_w}, (nm)}{\text{eff\_sweep}, (yds)} \right) * \left( \frac{2000\,yds}{1nm} \right) \right\rceil. \tag{5}$$

Equation 6 calculates the effective separation between sweeps called track separation. It can be shown through several runs of the model that the values for track separation and effective sweep width will be similar. This can be attributed to a constant sweep probability of one, a high level of MCM efficiency, and a clearance level close to one. By using a constant navigational error of 25 yards, and a minimum effective sweep width of 45 yards, the MCM efficiency will not be less than 1.38. Using an effective sweep width of 45 yards provides a 75% clearance level and a track separation of 45 yards. If the navigational error was increased or the sweep probability decreased, track separation

would decrease to a value less than that of effective sweep width. These types of values may be encountered in actual operational conditions and can be entered by the user.

$$\text{track\_sep, }(yds) = -\frac{(\text{eff\_sweep, }(yds) * \text{sweep\_prob} * \text{mcm\_eff})}{\ln(1 - \text{clear\_lvl})}. \tag{6}$$

Equation 7 calculates the number of missions available per day. This calculation is based on the number helicopters available for the AMCM mission and the hours of useable daylight. Only the integer value is returned because it is unlikely that partial missions would be flown.

$$\text{missions\_per\_day} = \tag{7}$$

$$= \left\lfloor \frac{\text{day\_time, }(hr)}{\text{mission\_time,}(hr) + \left(\text{refuel\_time,}(min) * \frac{1\ hr}{60\ min}\right)} \right\rfloor * \text{helo\_avail}.$$

Equation 8 calculates the effective mission time available to devote directly to the actual sweeping of the MDA. This value is used to determine ETOTITL time per sortie. Effective mission time contains the time available to sweep and turn the towed vehicle; all other related times have been removed.

$$\text{eff\_miss\_time, }(hr) = \tag{8}$$

$$= \text{mission\_time,}(hr) - \left(2 * \text{stream\_time,}(min) * \frac{1\ hr}{60\ min}\right)$$

$$- \left(2 * \frac{\text{trans\_dist, }(nm)}{\text{trans\_vel,}(kt)}\right) - \left(\text{t\_around\_time,}(min) * \frac{1\ hr}{60\ min}\right).$$

Equation 9 calculates ETOTITL, time required to sweep a single section including the time required to turn the towed vehicle.

$$\text{etotitl\_sec}, (hr) = \tag{9}$$

$$= (-1) * \left[ \frac{\text{channel\_w}, (nm) * \ln(1 - \text{clear\_lvl})}{\text{eff\_sweep}, (yd) * \text{sweep\_prob} * \text{mcm\_eff}} * \frac{2000\, yd}{1\, nm} \right]$$

$$* \left[ \frac{\text{section\_len}, (nm)}{\text{sweep\_vel}, (kt)} + \left( \text{time\_to\_turn}, (min) * \frac{1\, hr}{60\, min} \right) \right] * \text{ship\_count}\,.$$

Equation 10 calculates ETOTITL for the entire MDA. This equation simply multiplies the ETOTITL per section by the number of sections.

$$\text{etotitl}, (hr) = \text{etotitl\_sec}, (hr) * \text{num\_sec}\,. \tag{10}$$

Equation 11 calculates the number missions required to sweep the entire MDA. This value is not required to be an integer because the sweeping evolution can end any time during a specific sortie.

$$\text{num\_missions\_req} = \frac{\text{etotitl}, (hr)}{\text{eff\_miss\_time}, (hr)}\,. \tag{11}$$

Equation 12 calculates the number of days expected to clear the entire MDA. It should have become apparent that these equations do not account for any MTBF rates. Component failure rates will be addressed during the decision making process.

An assumption was also made concerning any logistics transfer that may take place. The user will enter the estimated number of days required to complete a one-way logistics transfer. The model does not differentiate between supplies, components or personnel for transfer. The user simply estimates the total time required (in days) to

complete a one-way logistics transfer. The model also assumes that the logistics will take approximately the same amount of time prior to the mission as well as after the mission has been completed.

$$\text{days\_to\_clear} = \frac{\text{num\_missions\_req}}{\text{missions\_per\_day}} + (2 * \text{log\_xfer\_days}). \tag{12}$$

Sample calculations for the equations above, utilizing the data from the INPUT column of Table 1 are located in Appendix B. The results are shown in the OUTPUT column of Table 1.

# IV. MODEL EXPLORATION

## A. OUTLINE AND GUIDANCE

The basic outline for exploring the model will be to start with organic operations, generate an effective sweep width and then vary the distance from the mother-ship to the MDA. Then using that same effective sweep width, explore lily-pad and cross-deck operations. The next step will be to perform the same model explorations for an effective sweep width of approximately 45 yards, 90 yards, 250 yards, and 500 yards. The 45-90 yard range is representative of the expected effective sweep widths for SWIMS and the 250-500 yard range is representative of the current MK-106 suite. [Ref. 6]

Table 2 displays the input data used for the first portion of model exploration. Transit distance is displayed as 50 nm however, as shown in the analysis below, the distance was varied between 50 nm and 150 nm in increments of 50 nm. A point of interest in the table is the time required for refueling the helicopter between individual sorties. An assumption is made to standardize refueling time at 12 minutes on the large-deck ships and 10 minutes on the small-deck ships. The refueling time varies by refueling platform and by individual ship on a day-to-day basis. The refueling times listed above are realistic averages.

INPUT

| | |
|---|---|
| Channel_w, (nm) | 0.50 |
| Area_len, (nm) | 180.20 |
| Section_len, (nm) | 5.00 |
| Ship_count | 10 |
| Sweep_vel, (kts) | 22 |
| Depth | 1 |
| Nav_error, (yds) | 25 |
| Time_to_turn, (min) | 3.0 |
| Mcm_density | 1 |
| Helo_avail | 4 |
| Trans_dist, (nm) | 50.0 |
| Trans_vel, (kts) | 110 |
| Refuel_time, (min) | 12.0 |
| Stream_time, (min) | 15.0 |
| t_around_time, (min) | 10.0 |
| Mission_time, (hrs) | 3.5 |
| Day_time, (hrs) | 12.0 |
| Log_xfer_days, (days) | 0.0 |

**Table 2. Model Exploration, Data Set 1. Organic AMCM transit distances from 50 nm to 150 nm, 15 nm lily-pad transit distance, 5 nm cross-deck transit distance, and 1 day for one-way logistics transfer.**

The numbers of days required to complete the logistics transfer, (log_xfer_days) is set to zero for organic and lily-pad operations. When calculating the number of days to sweep an MDA for cross-deck operations, a value of 1 day will be used. This value provides an initial estimation, which can be refined by the operational commander.

Figure 3 represents a possible tactical application to the data used from Table 3. It was assumed that the transiting units would maintain a constant distance from the starting point of the section(s) being swept. That is, as a portion of the MDA was

considered cleared, the ship conducting the sweeping operations would close the unswept portion maintaining a constant transit distance.

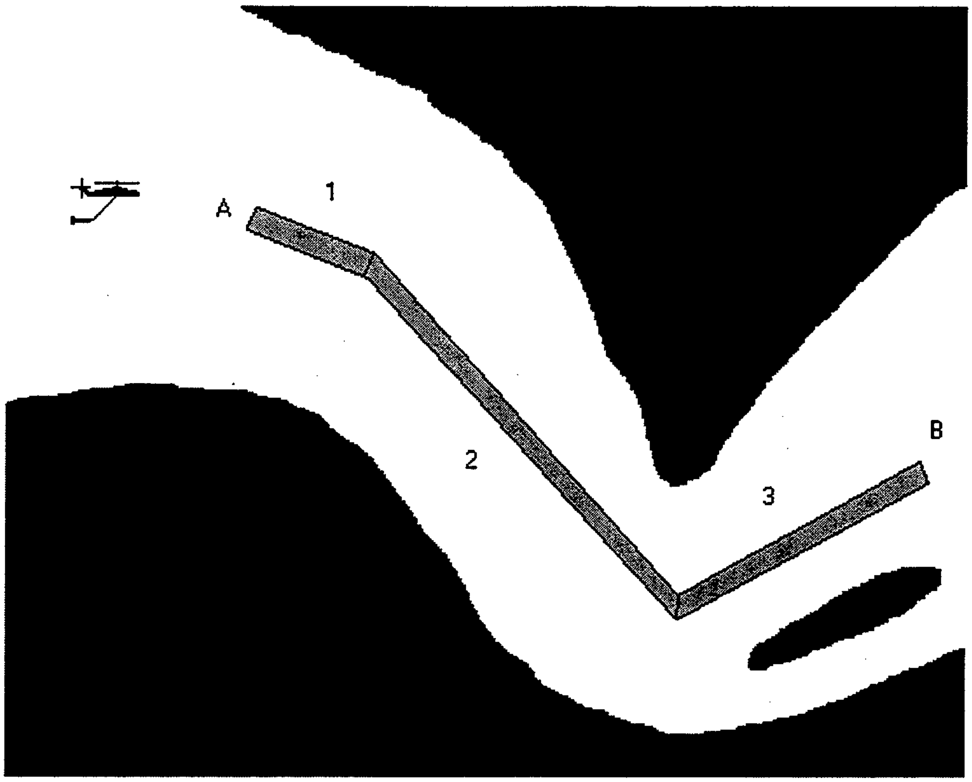


**Figure 3: Map for Data Set 1. Swept channel starts at Point A and terminates at Point B. Sections 1 through 3 depict the straight-line path for the channel.**

Figure 3 represents a single swept lane through an MDA. Point A is the initial entry point and Point B is the intended exit point. Sections 1 through 3 depict the straight-line path selected for the channel.

### 1. Organic Operations

#### *a. "Near" Operations*

"Near" operations will consider organic AMCM operations occurring with a transit distance of 125 nm or less from the mother ship. This type of organic

AMCM operation could be interpreted as a realistic alternative sweeping method to lily-pad or cross-deck operations even if small-deck combatants are available for lily-pad or cross-deck AMCM operations.

#### *b. "Far" Operations*

"Far" operations will consider organic AMCM operations with transit distances greater than 125 nm from the mother ship. This type of AMCM operation would primarily be considered only when lily-pad or cross-deck platforms were not available.

### 2. Lily-pad Operations

The transit distance for lily-pad operations was fixed at 15 nm from the MDA. Varying the distance between the mother ship and the lily-pad ship was not modeled because this transit distance was not included in the time-to-sweep calculations. We assume there is not a requirement for a personnel transfer in order to operate any equipment from the lily-pad ship. Because of this assumption, the initial and final transit to and from the mother ship can be accomplished during the hours of darkness, this transit method would not impact mission time. This assumption does not alter the time-to-sweep calculations outlined in chapter three.

### 3. Cross-deck Operations

For cross-deck operations we assume a constant transit distance to the MDA of 5 (nm). This should be a realistic assumption given the small-deck combatants have a much shallower draft than the large-decked mother ship. As stated earlier, one-way logistics transfer time will be fixed at a value of 1 day.

## B. DATA SET 1 OBSERVATIONS

Table 3 shows the results of the model exploration stated above. The abbreviation sw: ## represents the effective sweep widths used in the calculations: 45 yds, 90 yds, 250 yds, and 500 yds accordingly.

| Transit Distance, nm | sw:45 | sw:90 | sw:250 | sw:500 |
|---|---|---|---|---|
| 50 | 98.7 | 49.4 | 17.8 | 8.8 |
| 75 | 129.3 | 64.6 | 23.3 | 11.6 |
| 100 | 187.1 | 93.6 | 33.7 | 16.7 |
| 125 | 338.9 | 169.4 | 61 | 30.2 |
| 150 | 1791.3 | 895.6 | 322.4 | 159.5 |
| Lily-pad: 15 | 74.2 | 37.1 | 13.4 | 6.6 |
| Cross-deck: 5 | 71.3 | 36.6 | 14.5 | 8.2 |

**Table 3. Comparison of Days Required to Sweep, 4 Helicopters Available. Sweep Widths (sw) represented are: 45 yds, 90 yds, 250 yds, and 500 yds.**

Figure 4 graphically demonstrates the data in Table 4 and shows how the number of days required to sweep a given MDA varies by transit distance and effective sweep width.

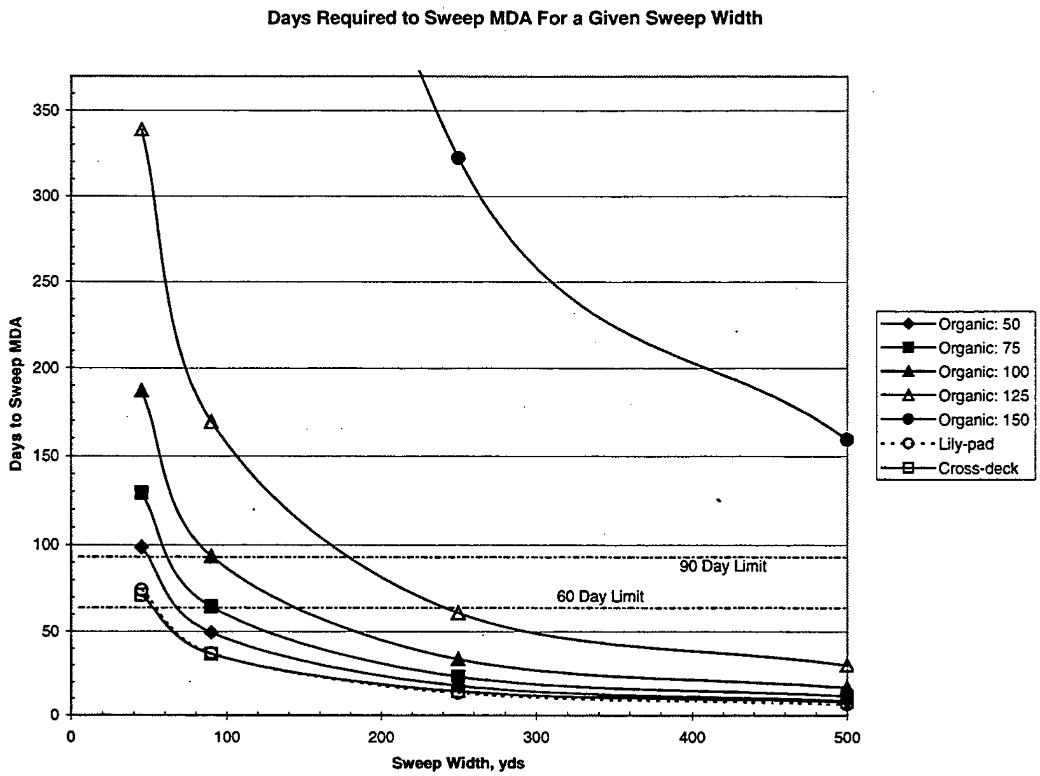


**Figure 4: 4 Helicopters Available, Organic and Other. Number of days required to sweep a 180 nm channel are depicted for organic transit distances of 50 nm to 150 nm, and lily-pad and cross-deck transit distances of 15 nm and 5 nm respectively.**

Legend interpretation for Figure 4 also applies to all future graphs. For example, Organic: 50, indicates that organic AMCM operations a being conducted with a transit distance of 50 nm. The reason for the earlier separation into "far" and "near-organic" AMCM operations can be seen in Figure 4. Transit distances greater than 125 nm do not allow sufficient ETOTITL unless small-deck combatants are available for lily-pad or cross-deck operations.

Figure 4 also shows that with the current MH-53/MK-106 system represented by effective sweep widths between 250 yards and 500 yards, transit distances of up to 125 nm

still allow a reasonable time to clear this large area MDA. This is based on a mission time of only 3.5 hours, the expected mission time of the CH-60. With the proposed SWIMS gear expected to have an effective sweep width of 45 to 90 yards and a expected mission time of 3.5 hours, the maximum transit distance shrinks to approximately 75 nm if the mission is expected to be completed in a reasonable amount of time (60 to 90 days). The 60-Day and 90-Day Limit lines in Figure 4 are there to indicate this practical operational limit to committing AMCM forces to a single task.

A time period greater than 90 days can create several problems. Most significant of these would be the enemy's ability to re-seed the MDA. Another significant problem is tactical continuity. 90 days is approximately the maximum amount of time to have individual operational units assigned to a specific mission. After this time, operational units would need to relinquish AMCM mission duties to other units in the area. Reasons for this turnover usually involve things such as required maintenance and crew fatigue.

Figure 5 provides an expanded view of the 45 – 90 yard effective sweep width calculations. Here the similar results of lily-pad and cross-deck can be visually separated.

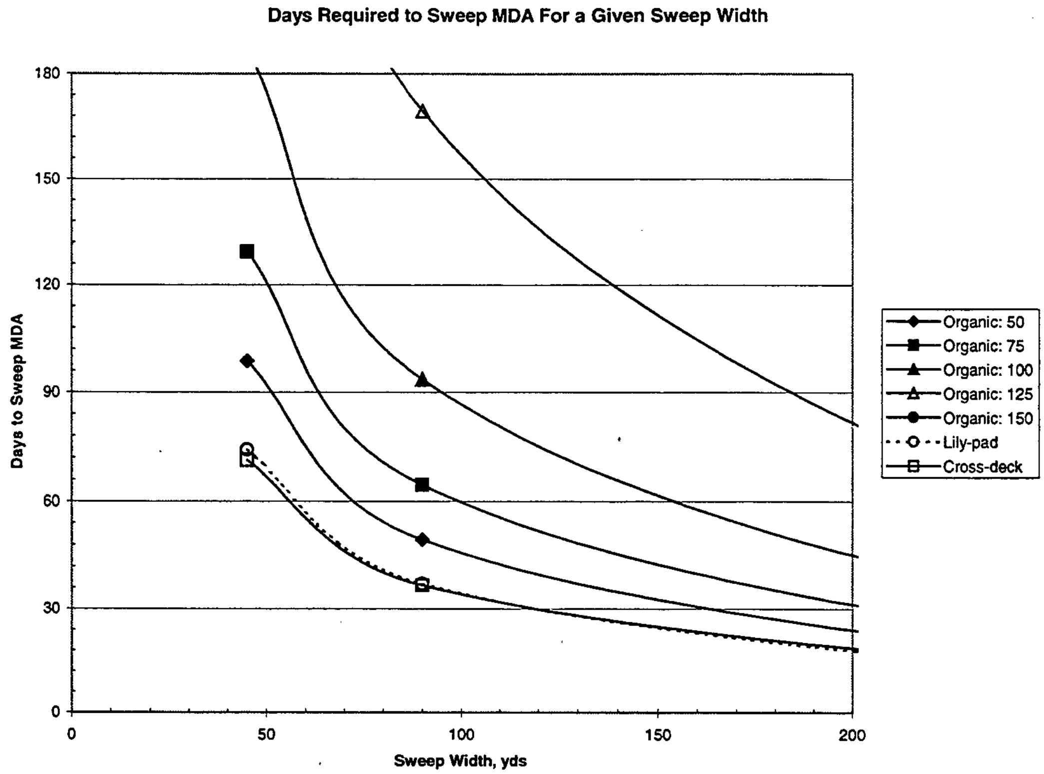


**Figure 5: Expansion of Figure 4. Demonstrates the similarity in sweep results for lily-pad and cross-deck AMCM operations.**

Figure 5 also shows the difference between "near-organic" and "far-organic" AMCM operations. Displaying the expected effective sweep width range for SWIMS and allowing for 180 days to sweep the area, the Organic: 150 line is not even displayed.

Data Set 1 should be viewed as an extreme case. The conditions for sweeping are far from favorable. A sweep channel over 180 nm in length that is in close proximity to land on both sides presents tactical problems such as defense of the AMCM helicopters which is beyond the scope of this thesis. Data Set 2 provides a scenario that is not as asset and time intensive as that of Data Set 1. The remainder of the results from the exploration of Data Set 1 are contained Appendix C.

## C. DATA SET 2

Data set 2 looks at a sweeping situation where there is a common entry point with multiple objectives for exit points. Figure 10 represents this tactical possibility. Point A is the common entry point, and Points 1 through 3 are the intended sweep channel exit points.

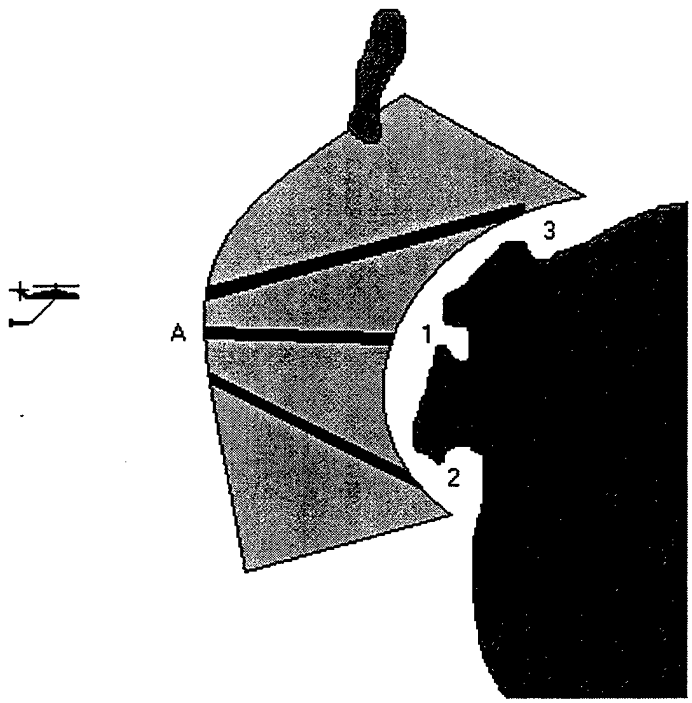


**Figure 6: Map for Data Set 2. Swept channel starts at Point A and terminates at Points 1 through 3, depending on the number of operational objectives.**

For Data Set 2, two options were explored. The first option considered only sweeping one channel, from Point A to Point 1. The second option explored sweeping two channels, from Point A to points 1 and 2. This data set looked at shorter channel lengths and the shorter sweep times associated with a smaller area to cover. The channel

from Point A to Point 3 was not used for Data Set 2 because the total length of area to sweep then approached the length of Data Set 1.

The channel from Point A to Point 1 has an assigned length of 45 nm, and the length of the second channel was set at 60 nm. Table 8 shows the data used to explore the first channel of Data Set 2. Data Set 2 was set up similar to Data Set 1, the transit distance from the organic ship was varied from 50 nm to 150 nm in increments of 25 nm, the transit distance for lily-pad operations was set at 15nm, and the transit distance for cross-deck operations at 5 nm.

| INPUT | |
|---|---|
| channel_w, (nm) | 0.50 |
| area_len, (nm) | 45.0 |
| section_len, (nm) | 5.00 |
| ship_count | 10 |
| sweep_vel, (kts) | 22 |
| depth | 1 |
| nav_error, (yds) | 25 |
| time_to_turn, (min) | 3.0 |
| mcm_density | 1 |
| helo_avail | 4 |
| trans_dist, (nm) | 50.0 |
| trans_vel, (kts) | 110 |
| refuel_time, (min) | 12.0 |
| stream_time, (min) | 15.0 |
| t_around_time, (min) | 10.0 |
| mission_time, (hrs) | 3.5 |
| day_time, (hrs) | 12.0 |
| log_xfer_days, (days) | 0.0 |

**Table 4. Model Exploration, Data Set 2. Single channel length is 45 nm representing a swept channel from Point A to Point 1. Dual channel length is 105 nm representing swept channels from Point A to Point 1 and Point A to Point 2. All other is similar to that in Data Set 1.**

## D. DATA SET 2 OBSERVATIONS

Table 5 shows the number of days required to sweep the first channel for Data Set 2.

| Transit Distance, nm | sw:45 | sw:90 | sw:250 | sw:500 |
|---|---|---|---|---|
| 50 | 24.0 | 12.0 | 4.3 | 2.1 |
| 75 | 31.4 | 15.7 | 5.7 | 2.8 |
| 100 | 45.5 | 22.8 | 8.2 | 4.1 |
| 125 | 82.4 | 41.2 | 14.8 | 7.3 |
| 150 | 435.7 | 217.9 | 78.4 | 38.8 |
| Lily-pad: 15 | 18.1 | 9.0 | 3.3 | 1.6 |
| Cross-deck: 5 | 16.9 | 8.4 | 3.0 | 1.5 |

**Table 5. Data Set 2, First Channel Results, 4 Helicopters Available. Sweep Widths (sw) represented are: 45 yds, 90 yds, 250 yds, and 500 yds.**

Figure 7 graphically demonstrates the data in Table 5 and shows how the number of days required to sweep a given MDA varies by transit distance and effective sweep width for a shorter swept MDA channel. The distinction between "near" and "far-organic" operations is still apparent in the figure. Transiting more than 125 nm to sweep an MDA using SWIMS does not allow sufficient ETOTITL.

Days Required to Sweep MDA For a Given Sweep Width

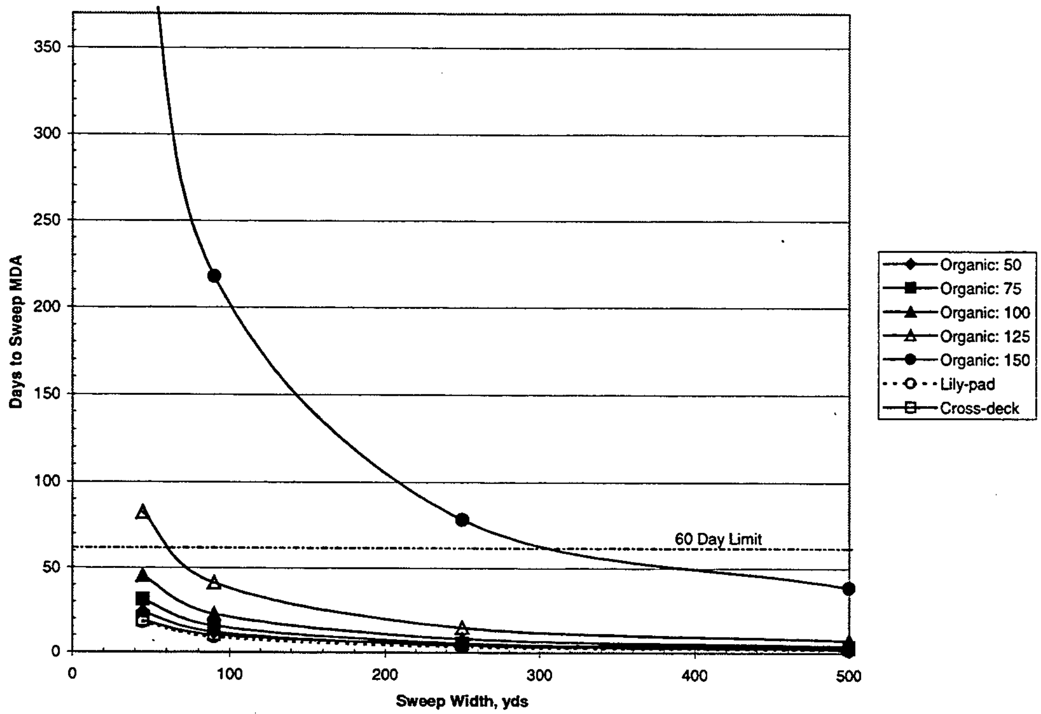


**Figure 7: One Sweep Lane, 4 Helicopters Available. Number of days required to sweep a 45 nm channel are depicted for organic transit distances of 50 nm to 150 nm, and lily-pad and cross-deck transit distances of 15 nm and 5 nm respectively.**

Figure 7 shows that the mother ship would be able to maintain a greater standoff distance from the MDA because of the smaller area required to be swept. Here, organic operations for SWIMS could be utilized out to a distance of approximately 125 nm while completing the mission within 90 days.

Table 6 shows the days required to sweep results of having 4 helicopters, organic or "other" to clear two lanes through the MDA depicted in Figure 6.

| Transit Distance, nm | sw:45 | sw:90 | sw:250 | sw:500 |
| --- | --- | --- | --- | --- |
| 50 | 56 | 28 | 10.1 | 5 |
| 75 | 73.4 | 36.7 | 13.2 | 6.5 |
| 100 | 106.2 | 53.1 | 19.1 | 9.5 |
| 125 | 192.3 | 96.2 | 34.6 | 17.1 |
| 150 | 1016.7 | 508.3 | 183 | 90.5 |
| Lily-pad: 15 | 42.1 | 21.1 | 7.6 | 3.7 |
| Cross-deck: 5 | 41.3 | 21.7 | 9.1 | 5.5 |

**Table 6. Two Lanes, 4 Helicopters Available. Sweep Widths (sw) represented are: 45 yds, 90 yds, 250 yds, and 500 yds.**

Figure 8 gives a graphical example of the data in Table 6. It depicts how the transit distance for organic AMCM operations must be reduced to keep the number of days required to sweep the area under the 60 or 90 day limit. Comparing Figures 7 and 8 show that as the length of the swept channel increases, organic transit distance must be reduced. Figure 8 shows how only the 75 nm and 50 nm transit distances meet the 90 day limit. All of the "near" transit distances stay under the 90 limit when the single, short channel is swept.

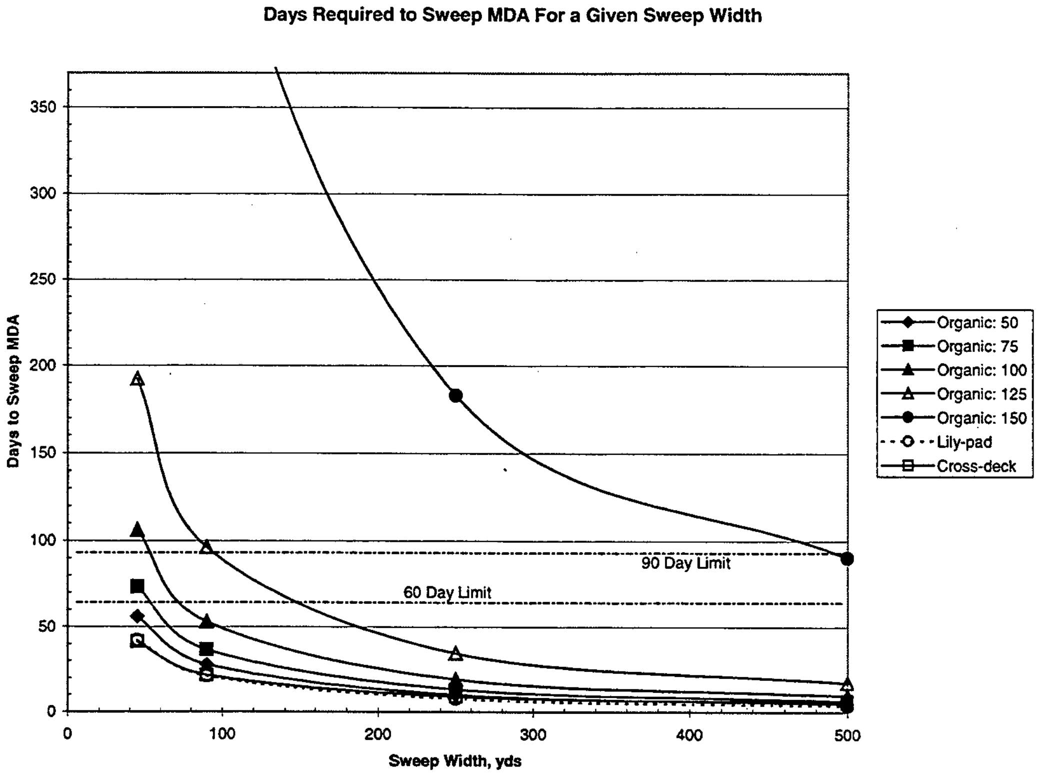


**Figure 8:** **2 Sweep Lanes, 4 Helicopters Available. Number of days required to sweep a total channel length of 105 nm are depicted for organic transit distances of 50 nm to 150 nm, and lily-pad and cross-deck transit distances of 15 nm and 5 nm respectively.**

Several variations of the employment model are explored and the details of exploring Data Set 2 can be found in Appendix D. These variations show the simple results that as the length of the swept channel increases, the operational commander must either employ more assets from small-deck combatants or move the mother-ship in closer to the MDA to shorten the transit distances for the organic AMCM helicopters. The results of the above variations will be combined as discussed in the Conclusions portion of this thesis.

## V. CALCULATIONS FOR NUMBER OF HELICOPTERS REQUIRED

If the operational commander desires to determine the number of helicopters required to sweep a given area from a selected transit distance, simple manipulation of some of the data output parameters will provide the number of air assets required. The input data will no longer contain the number of helicopters available, but will provide the number of days the user desires to spend sweeping the MDA. Table 7 shows how input and output change when the user desires to fix the number of days available for AMCM.

| INPUT | OUTPUT |
|---|---|
| channel_w, (nm) | #_sections |
| area_len, (nm) | eff_sweep, (yds) |
| section_len, (nm) | mcm_eff |
| ship_count | clear |
| sweep_vel, (kts) | turns |
| depth | sweep_prob |
| nav_error, (yds) | track_sep, (yds) |
| time_to_turn, (min) | eff_miss_time, (hrs) |
| mcm_density | Etotitl_sec, (hrs) |
| swp_days_avail, (days) | Etotitl, (hrs) |
| trans_dist, (nm) | helo_miss_per_day |
| trans_vel, (kts) | num_missions_req |
| refuel_time, (min) | miss_req_per_day |
| stream_time, (min) | num_helos_req |
| t_around_time, (min) | |
| mission_time, (hrs) | |
| day_time, (hrs) | |
| log_xfer_days, (days) | |

**Table 7. Input/Output For Number Of Helicopters Required.**

Output will change from the original model by providing the number of missions required to be flown per day in order to achieve mission success in the requisite number of

days and the number of helicopters required to perform the mission. This exploration of the original model only calculates the number of helicopters required based on a single transit distance. This method of calculation is the same as that of the original model. The original model only required minor perturbations to achieve the desired calculations.

The following data elements modify the original model in order to calculate the desired outcome specifying the number of helicopters required to sweep a given MDA within a set number of days:

| | |
|---|---|
| swp_days_avail | sweep days available, days. Predetermined number of days allowed to complete the AMCM mission for a given MDA. |
| helo_miss_per_day | number of missions available for a single helicopter to fly, based on available mission time, hours of day light, and refuel time. |
| miss_req_per_day | number of missions required to be flown per day in order to effectively sweep the MDA through completion in the prescribed number of days. |
| num_helos_req | number of helicopters required to complete the AMCM mission in the prescribed number of days. |

Equation 13 determines the missions that can be flown by a single helicopter in a day for the given conditions. These conditions are mission time, number of hours of day light, and refueling time. Only the integer value is returned because it is unlikely that partial missions would be flown.

$$\text{helo\_miss\_per\_day} = \tag{13}$$

$$= \left\lfloor \frac{\text{day\_time},(hr)}{\text{mission\_time},(hr) + \left(\text{refuel\_time},(min) * \frac{1\ hr}{60\ min}\right)} \right\rfloor .$$

Equation 14 calculates the number of AMCM missions required to be flown per day to effectively sweep the designated MDA. This equation takes the number of missions required from Equation 11 and divides by the number of days required for task completion. This value will be used to calculate the number of helicopters required for the entire sweeping operation along with the number of single helicopter missions available per day from Equation 13.

$$\text{miss\_req\_per\_day} = \frac{\text{num\_miss\_req}}{\text{sweep\_days\_avail}, \, (\mathit{days})}. \tag{14}$$

Equation 15 calculates the integer number of helicopters required to sweep the designated MDA in the allotted number of days.

$$\text{num\_helo\_req} = \left\lceil \frac{\text{miss\_req\_per\_day}}{\text{helo\_miss\_per\_day}} \right\rceil. \tag{15}$$

Sample calculations for the equations above can be found in Appendix E.

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# VI. CONCLUSIONS

## A. OBSERVATIONS

For the minesweeping scenario shown in Figure 3, Figures 4 and 5 and the data in Appendix C all show that it will not be possible to effectively complete sweeping operations in under sixty days using current predicted sweep-width performance of SWIMS. The scenario only becomes feasible as the effective sweep width approaches 90 yards and then, lily-pad or cross-deck operations will be necessary. It should be noted that 90 yards is an approximate upper-limit of the expected effective sweep width for SWIMS. Organic operations with the mother ship at 125 nm from the MDA will be feasible only with effective sweep widths of approximately 250 yards, the lower end of the current system's capability.

For the minesweeping scenario shown in Figure 6, the proposed SWIMS system becomes more feasible. Figure 8 and the data in Appendix D show that sweeping two lanes is possible within 60 days using lily-pad or cross-deck operations. If organic operations are preferred with the mother ship at least 125 miles from the MDA, again a minimum effective sweep width of 90 yards will be required.

The model results are summarized in tabular form in order to provide the operational commander the opportunity to make an informed tactical decision based on the results of the study. Tables 8-10 depict the results of the model exploration. Where all three methods are considered feasible within the required number of days, lily-pad or

cross-deck AMCM operations are given preference over organic operations to allow the high value unit or mother ship to maintain a safe standoff distance.

Another consideration given to the deployment methods of Table 8 is the differentiation between lily-pad and cross-deck AMCM operations. The data results from the Model Exploration chapter show that lily-pad and cross-deck sweep results are very similar in value. As the effective sweep width was increased from 45 yards to 500 yards, the 10-nm transit distance advantage for cross-deck operations was overcome by the 2-day logistic requirement. Therefore, the results contained in Tables 8-10 favor lily-pad operations when the number of days to sweep an MDA is approximately 30 days or less. It can be argued that an expected time-to-sweep of 30 days or less does not justify the logistics transfer operations when the results are so similar.

Tables 8 through 10 provide SWIMS implementation recommendation methods for the given conditions. The term "Equal Assets" indicate that it would always be preferential to utilize lily-pad or cross-deck operations over organic given the same number of helicopters are available for any of the three methods of SWIMS implementation.

| Tactical Situation | Primary Clearance Method | Secondary Clearance Method | Tertiary Clearance Method |
|---|---|---|---|
| **Short Channel Length: 45 nm, Equal Assets** | Lily-pad | Cross-deck | Organic |
| **Short Channel Length: 45 nm, 4-Organic, 1-Other** | Lily-pad | Cross-deck | Organic (100) |
| **Short Channel Length: 45 nm, 4-Organic, 2-Other** | Lily-pad | Cross-deck | Organic (75) |
| **Short Channel Length: 45 nm, 3-Organic, 1-Other** | Cross-deck | Lily-pad | Organic (100) |
| **Short Channel Length: 45 nm, 3-Organic, 2-Other** | Lily-pad | Cross-deck | Organic (50) |

**Table 8. AMCM Sweep Recommendations, Short Channel. Recommendations are primarily based on time-to-sweep calculations. If organic and non-organic sweep methods provided similar results, the non-organic method was recommended to allow the high value ship to maintain a safer distance from the MDA. The number in parenthesis (), indicates the minimum organic transit distance required to achieve similar sweep results to non-organic methods.**

| Tactical Situation | Primary Clearance Method | Secondary Clearance Method | Tertiary Clearance Method |
| --- | --- | --- | --- |
| **Medium Channel Length: 105 nm, Equal Assets** | Cross-deck | Lily-pad | Organic |
| **Medium Channel Length: 105 nm, 4-Organic, 1-Other** | Organic (100) | Cross-deck (H) | Lily-pad (H) |
| **Medium Channel Length: 105 nm, 4-Organic, 2-Other** | Cross-deck | Lily-pad | Organic (75) |
| **Medium Channel Length: 105 nm, 3-Organic, 1-Other** | Organic (75) | Cross-deck (H) | Lily-pad (H) |
| **Medium Channel Length: 105 nm, 3-Organic, 2-Other** | Cross-deck | Lily-pad | Organic (50) |

**Table 9. AMCM Sweep Recommendations, Medium Channel. Recommendations are primarily based on time-to-sweep calculations. If organic and non-organic sweep methods provided similar results, the non-organic method was recommended to allow the high value ship to maintain a safer distance from the MDA. The number in parenthesis (), indicates the minimum organic transit distance required to achieve similar sweep results to non-organic methods. The symbol (H) indicates that an effective sweep width near the expected 90-yard limit of SWIMS must be maintained for the operations to be feasible.**

| Tactical Situation | Primary Clearance Method | Secondary Clearance Method | Tertiary Clearance Method |
|---|---|---|---|
| **Long Channel Length: 180 nm, Equal Assets** | Cross-deck | Lily-pad | Organic |
| **Long Channel Length: 180 nm, 4-Organic, 1-Other** | Organic (75) | Cross-deck (I) | Lily-pad (I) |
| **Long Channel Length: 180 nm, 4-Organic, 2-Other** | Organic (50) | Cross-deck (H) | Lily-pad (H) |
| **Long Channel Length: 180 nm, 3-Organic, 1-Other** | Organic(50) | Cross-deck (I) | Lily-pad (I) |
| **Long Channel Length: 180 nm, 3-Organic, 2-Other** | Cross-deck | Lily-pad | Organic (50) |

**Table 10. AMCM Sweep Recommendations, Long Channel. Recommendations are primarily based on time-to-sweep calculations. If organic and non-organic sweep methods provided similar results, the non-organic method was recommended to allow the high value ship to maintain a safer distance from the MDA. The number in parenthesis (), indicates the minimum organic transit distance required to achieve similar sweep results to non-organic methods. The symbol (H) indicates that an effective sweep width near the expected 90-yard limit of SWIMS must be maintained for the operations to be feasible. The symbol (I) indicates the AMCM sweep method is infeasible within the 90-day limit.**

## B. SWIMS IMPLEMENTATION TACTICAL CONCERNS

SWIMS is expected to have an effective sweep width range of approximately 20% of the current MK-106 suite. To offset the reduced coverage of the current system, SWIMS planners must rely on the mobility, number of deployable units, and ease of employment of the SWIMS system. The number of SWIMS capable helicopters in a particular theater of operations is expected to be 4 CH-60 helicopters per carrier battle group and 4 CH-60 helicopters per amphibious readiness group.

The expected number of CH-60 employed SWIMS systems available to the operational commander for a given tactical scenario can be compared to the requirements shown in Table 11. Table 11 provides the results of the number of helicopters required to effectively sweep a given channel length using the basic input values from the Model Exploration chapters and appendices. The number of helicopters required for the operations study below is also based on an effective sweep width of 90 yards and time to complete the mission of 60 days.

| | | Channel Length | |
|---|---|---|---|
| Transit Distance, nm | 180 nm | 105 nm | 45 nm |
| 150 | 58 | 34 | 15 |
| 125 | 11 | 7 | 3 |
| 100 | 6 | 4 | 2 |
| 75 | 4 | 3 | 1 |
| 50 | 3 | 2 | 1 |
| Lily-pad: 15 | 3 | 2 | 1 |
| Cross-deck: 5 | 2 | 1 | 1 |

**Table 11. Helicopters Required, 60-Day Limit, 90 yd Effective Sweep. The number of helicopters required to sweep a given channel length with a consistent effective sweep width of 90 yards is shown. A 90 yard sweep width is the expected upper limit for SWIMS.**

The data represented in Table 11 is based on a constant effective sweep width of 90 yards. Actual effective sweep width for SWIMS is expected to achieve that value under certain conditions. Table 12 shows the results of a 45-yard effective sweep width. As expected, the number of helicopters required to sweep the region within the 60 day limit quickly approach infeasible numbers as the transit distance is increased for all channel lengths.

| Transit Distance, nm | 180 nm | Channel Length<br>105 nm | 45 nm |
|---|---|---|---|
| 150 | 116 | 68 | 29 |
| 125 | 22 | 13 | 6 |
| 100 | 12 | 7 | 3 |
| 75 | 9 | 5 | 3 |
| 50 | 7 | 4 | 2 |
| Lily-pad: 15 | 5 | 3 | 1 |
| Cross-deck: 5 | 5 | 3 | 1 |

**Table 12. Helicopters Required, 60-Day Limit, 45 yd Effective Sweep. The number of helicopters required to sweep a given channel length with a consistent effective sweep width of 45 yards is shown. A 45 yard sweep width is the expected lower limit for SWIMS.**

With an effective sweep of only 45 yards, it would take two CH-60 detachments of 4 helicopters each to sweep the 180-nm channel from a transit distance of 50 nm or while operating from small-deck combatants. The shorter channel lengths can be swept with fewer assets, or at greater distances. Giving SWIMS a greater effective sweep width would require the use of fewer assets and allow completion of the AMCM operation in a shorter amount of time. Comparing the results of Table 11 and Table 12 shows the advantage of larger sweep widths. Unless several small-decks can be tasked for an extended amount of time, sweeping a large-channel MDA becomes infeasible.

The tables above point out the importance of utilizing small-deck combatants during large-area MDA AMCM sweeping operations. The CH-60 currently cannot operate from small-deck combatants utilizing the cross-deck method. There is no method available to maneuver the helicopter in and out of the hangar. Leaving the helicopter out on the exposed flight deck for extended periods of time would severely corrode most of

the helicopter and its components. This would also prohibit any other flight operations from being conducted from that ship. A method of maneuvering the helicopter in and out of the hangar must be devised in order to deploy SWIMS and take advantage of cross-deck operations.

## C. RECOMMENDATIONS FOR FURTHER STUDIES

Current model exploration considered the number of days required to complete the mission as the primary Measure of Effectiveness (MOE) to consider. Table 8 also provides consideration for survival of the mother ship, but only when the other two employment methods have similar time-to-sweep values. This assumption was subjective.

The three types of AMCM employment could be compared over a range of MOE's. These MOE's should be quantified, ranked in terms of relative importance, and presented to the decision-maker in a manner conducive to assessing the current operational situation. A small example of a sample decision table is provided in Table 13.

The fact that these MOE's conflict with each other is demonstrated in the table above. To read the table, consider one of the MOE's as fixed, and compare the employment methods under this MOE. For example, take Mother Ship Survivability. The mother ship has a relatively higher survival probability the farther it is from a potentially hostile coastline. Using organic operations would require the mother ship to operate close to the MDA and the coastline relative to the remaining two employment methods, this would make the mother ship vulnerable to hostile fire.

| | Days to Complete Mission | Mother Ship Survivability | Reliability | A/C Rescue |
|---|---|---|---|---|
| **Organic Operations** | Worst | Worst | Best | Best |
| **Lily-pad Operations** | Intermediate | Intermediate | Worst | Intermediate |
| **Cross-deck Operations** | Best | Best | Intermediate | Worst |

**Table 13. Decision Table. Shows a technique for comparing SWIMS implementations methods for different MOE's.**

Similar logic leads to the remaining entries in the table. For example, during organic AMCM operations, if the mother ship maintains a safe distance from the MDA, the transit time to and from the MDA severely reduces the time remaining to conduct AMCM. Conversely, if organic AMCM operations were being conducted, the ability to rescue a downed aircrew would not be hampered by the AMCM mission. There would also be a significant number of rescue platforms available on the mother ship while lily-pad or cross-deck operations would be restricted to at most two rescue platforms. A rescue mission from one of the small-deck ships would restrict the ability to simultaneously conduct the AMCM mission.

These and possibly additional MOE's could be explored, quantified, and ranked in terms of importance. Uncertainty in airborne mine clearing operations could then be explored. Some notable uncertainty issues are helicopter availability due to mission-

equipment failure and helicopter inspection cycles. Uncertainty relating to tactical assumptions such as environmental conditions and sweep effectiveness may also be explored.

# APPENDIX A. PACK-UP-KIT AUGMENTATION RECOMMENDATIONS

When preparation for this thesis was started, pack-up-kits for deploying LAMPS detachments was dependant on number of helicopters assigned to the detachment, the type of ship the detachment was assigned to, and the region the ship and detachment were deploying to. Since then, PUK's have been standardized and are capable of handling most component failures associated with the SH-60B. [Ref. 7] SH-60F helicopters deploy as a squadron aboard ships that have on-board intermediate level maintenance and do not require PUK's. The deployment of CH-60 helicopter detachments aboard aircraft carriers or amphibious assault ships will most likely require an augmentation of specialized parts and components to the ships internal supply system.

The internal supply system augmentation list for SWIMS will be controlled by the appropriate program offices and warfare commanders, and is beyond the scope of this study. What may be helpful to the aircraft commander, or SWIMS detachment OIC tasked with detaching helicopters for extended AMCM operations is a list of mission-specific items and consumables that would provide a SWIMS detachment with a level of replacement parts sufficient to maintain extended operations from a small-deck ship.

The list below should not be considered complete but may prove useful to a planner preparing a SWIMS detachment for extended operations from a small-deck combatant:

1. High-speed input shaft, (1)
2. Weight kit for balancing the high-speed shaft flex couplings, (1)

3. Environmental Control Unit (ECU), (1)
4. Intermediate Gear Box, (1)
5. Tail Gear Box, (1)
6. Tail-rotor Pitch Change Rods (PCR), (2)
7. Main-rotor PCR, (1)
8. Tail-rotor Pitch Change Coupling, (2)
9. Main-rotor Pitch Change Coupling, (1)
10. Main-rotor Bifilar, (1)
11. Igniters, (3)
12. Starter, (1)
13. Turn-rate gyro, (1)
14. BDHI, (1)
15. AFCS computer, (1)
16. Battery, (1)
17. Radar altimeter, (1)
18. Blade-fold motor, (1)
19. Main-mount wheel and tire assembly, (1)
20. Tail-wheel and tire assembly, (1)
21. Bore-scope, (1)
22. VATS computer with extra boot-disk, (1)
23. VATS cables and connectors, (complete set)
24. Engine oil, (several quarts)

25. Hydraulic fluid, (several quarts)
26. Aerosol aircraft cleaner, (enough for at least one a/c wash per week of expected detached operations, 4 weeks-worth max)
27. Clean rags, (1 bale)
28. Tow cable, (1)
29. Tow cable attachment stirrup, (1)
30. SWIMS power cable, (1)
31. Additional SWIMS-specific mission equipment that subject to a high-rate of loss or breakage.

As stated this list should not be considered inclusive but should give the planner a place to start. Components like seals to bring along would dependant on expected region-specific weather conditions. The idea behind the above list is keep from placing too great of a strain on the host-ship's internal supply system. Small-deck combatants are very limited on the amount of helicopter-replacement parts are carried. Basically, the more components and equipment a SWIMS detachment could bring with them, the better off they would be if something would break and, something always breaks.

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# APPENDIX B. SAMPLE CALCULATIONS, TIME-TO-SWEEP

Using the data from Table 1, and the equations above, the following provides a numerical example for the model. The model was created using Microsoft Excel '97.

Equation 1 ...

area_len, (nm) = 180.2, section_len, (nm) = 5.00,

$$\text{num\_sections} = \frac{180.2}{5.00} = \lceil 36.04 \rceil = 37 \qquad (1)$$

Effective sweep, (yds), was generated using Equation 2 and the Insight add-in for Microsoft Excel.

Equation 2 ...

$$\text{eff\_sweep, (yds)} = 74.78\ . \qquad (2)$$

Equation 3 ...

eff_sweep, (yds) = 74.78, nav_error, (yds) = 25,

$$\text{mcm\_eff} = \exp\left[0.0007 + 0.1807 * \left(\frac{74.78}{25}\right)\right] = 1.7181\,. \qquad (3)$$

Equation 4 ...

mcm_density = 1, mcm_eff = 1.7181,

$$\text{clear\_lvl} = 1 - \exp(-1 * 1.7181) = 0.8206\,. \qquad (4)$$

Equation 4 shows that for the given conditions, approximately 82% percent of ship count one mines will have been successfully swept by the first sweep of the MDA.

Equation 5 ...

channel_w, (nm) = 0.5, eff_sweep, (yds) = 74.78,

$$\text{turns} = \left(\frac{0.5}{74.78}\right) * \left(\frac{2000\ yds}{1\ nm}\right) = \lceil 13.37 \rceil = 14\,. \tag{5}$$

Equation 6 ...

eff_sweep, (yds) = 74.78, sweep_prob = 1,

mcm_eff = 1.7181, clear_lvl = 0.8206,

$$\text{track\_sep, } (yds) = -\left[\frac{74.78 * 1 * 1.7181}{\ln(1 - 0.8206)}\right] = 74.78\,. \tag{6}$$

Equation 7 ...

day_time, (hr) = 12.0, mission_time, (hr) = 3.5,

refuel_time, (min) = 12.0, helo_avail = 4,

$$\text{missions\_per\_day} = \left\lfloor \frac{12.0}{3.5 + \left(12.0 * \frac{1\ hr}{60\ min}\right)} \right\rfloor * 4 = 12\,. \tag{7}$$

Equation 8 ...

mission_time, (hr) = 3.5, stream_time, (min) = 15.0,

trans_dist, (nm) = 50.0, trans_vel, (kts) = 110,

t_around_time, (min) = 10.0,

$$\text{eff\_miss\_time, } (hr) = 3.5 - \left(2 * 15.0 * \frac{1hr}{60min}\right) - \left(2 * \frac{50.0}{110}\right) \tag{8}$$

$$- \left(10.0 * \frac{1hr}{60min}\right) = 1.9242\,.$$

Equation 8 shows an effective mission time of 1.9 hours, this value could vary from as high as 2.7 hours for a cross-deck evolution maintaining a 5 nm stand-off from

the MDA, to as low as 6 minutes if a 150 nm stand-off is maintained. It is not unreasonable to consider an effective mission time of less than 30 minutes to be reason for an operational commander to either move the ship closer to the MDA or use the air assets for other operational tasking. A minimum effective mission time of 30 minutes equates to a maximum distance of 128.3 nm.

Equation 9 ...

channel_w, (nm) = 0.5, clear_lvl = 0.8206,

eff_sweep, (yds) = 74.78, sweep_prob = 1,

mcm_eff = 1.7181, section_len, (nm) = 5.00,

sweep_vel, (kt) = 22, time_to_turn, (min) = 3.0,

ship_count = 10,

$$\text{etotitl\_sec},(hr) = (-1)*\left[\frac{0.5*\ln(1-0.8206)}{74.78*1*1.7181}*\frac{2000\ yds}{1\ nm}\right]* \tag{9}$$

$$\left[\frac{5.00}{22}+\left(3.0*\frac{1\ hr}{60\ min}\right)\right]*10 = 37.0789\,.$$

Equation 10 ...

etotitl_sec, (hr) = 37.0789, num_sections = 37,

$$\text{etotitl},(hr) = 37.0789*37 = 1371.9191\,. \tag{10}$$

It is coincidental that the value for ETOTITL per section, 37.1 and the number of sections, 37 are similar. The time required to sweep a given section, ETOTITL, is dependant on the size of the section, not how many of the sections there are.

Equation 11 ...

etotitl, (hr) = 1371.9191, eff_miss_time, (hr) = 1.9242,

$$\text{num\_missions\_req} = \frac{1371.9191}{1.9242} = 712.9816\,. \tag{11}$$

Equation 12 ...

A value of zero is used for log_xfer_days because the sample calculations represent organic AMCM operations. It is assumed that lily-pad operations would require minimal or no logistics transfer and that cross-deck operations would require approximately one day prior to AMCM operations and one day after sweeping has been completed for logistics transfer.

num_miss_req = 712.9816, missions_per_day = 12,

log_xfer_days = 0.0,

$$\text{days\_to\_clear} = \frac{712.9816}{12} + 0.0 = 59.4151\,. \tag{12}$$

## APPENDIX C. DETAILED EXPLORATION OF DATA SET 1

The next issue to look at is the very real possibility that there will only be one or two helicopters available for either cross-deck or lily-pad operations. Additionally, the operational commander may not want to devote all 4 helicopters to AMCM for 15 to 90 days. Therefore, the number of helicopters available for the AMCM mission will be varied. We look at the deployment possibilities of 4 organic helicopters versus 1 or 2 helicopters deployed by lily-pad or cross-deck methods and then 3 organic helicopters versus 1 or 2 "other" helicopters.

Table 14 depicts the availability of 4 organic helicopters versus one helicopter available for lily-pad or cross-deck operations. The data used in these and subsequent calculations for Data Set 1 can be found in Table 3.

| Transit Distance, nm | sw:45 | sw:90 | sw:250 | sw:500 |
|---|---|---|---|---|
| 50 | 98.7 | 49.4 | 17.8 | 8.8 |
| 75 | 129.3 | 64.6 | 23.3 | 11.6 |
| 100 | 187.1 | 93.6 | 33.7 | 16.7 |
| 125 | 338.9 | 169.4 | 61 | 30.2 |
| 150 | 1791.3 | 895.6 | 322.4 | 159.5 |
| Lily-pad: 15 | 296.8 | 148.4 | 53.4 | 26.4 |
| Cross-deck: .5 | 279.1 | 140.6 | 51.9 | 26.7 |

**Table 14. 4-Organic, 1-Other Helicopter Available.**

Figure 9 provides a graphic representation of the data in Table 4. It shows that with only one helicopter available for lily-pad or cross-deck operations, the number of days to sweep an MDA favor organic operations out to a maximum transit distance of 75

nm. The MDA is too large for one helicopter to effectively sweep in a reasonable amount of time, even if the helicopter can operate as close as 5 nm from the MDA.

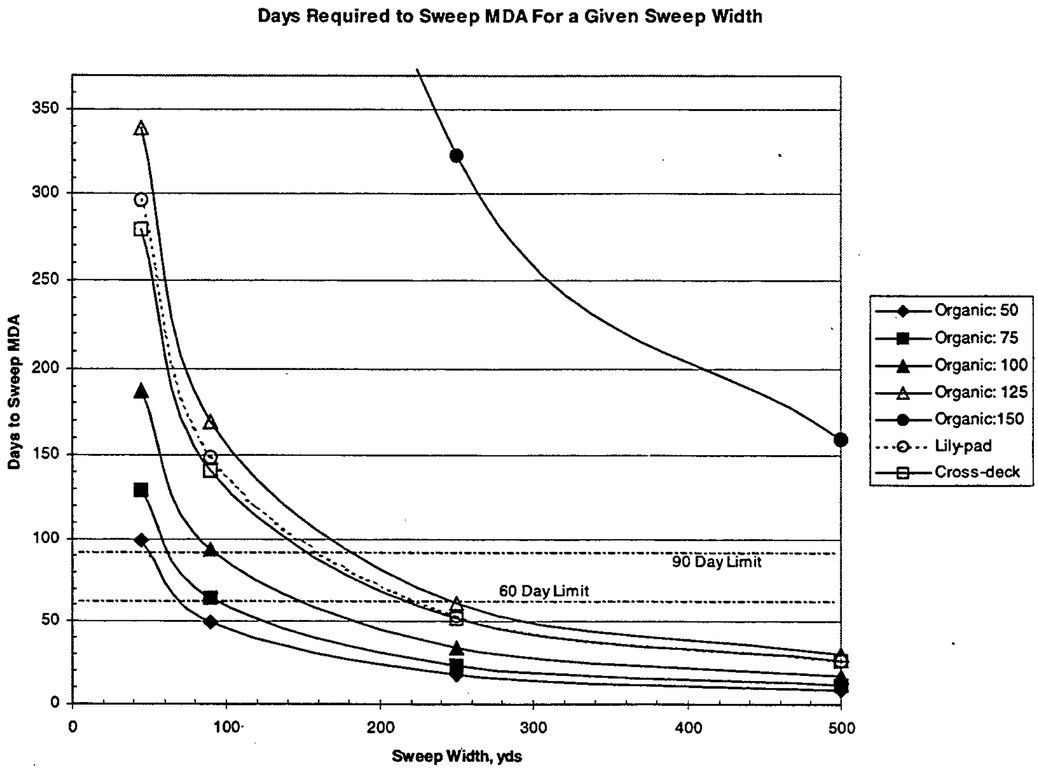


**Figure 9: 4-Organic, 1-Other Helicopters Available.**

Table 15 provides the results of comparing 4 organic helicopters versus 2 lily-pad or cross-deck helicopters. Figure 10 provides a graphical representation of Table 5.

| Transit Distance, nm | sw:45 | sw:90 | sw:250 | sw:500 |
|---|---|---|---|---|
| 50 | 98.7 | 49.4 | 17.8 | 8.8 |
| 75 | 129.3 | 64.6 | 23.3 | 11.6 |
| 100 | 187.1 | 93.6 | 33.7 | 16.7 |
| 125 | 338.9 | 169.4 | 61 | 30.2 |
| 150 | 1791.3 | 895.6 | 322.4 | 159.5 |
| Lily-pad: 15 | 148.4 | 74.2 | 26.7 | 13.2 |
| Cross-deck: 5 | 140.6 | 71.3 | 26.9 | 14.3 |

**Table 15. 4-Organic, 2-Other Helicopters Available.**

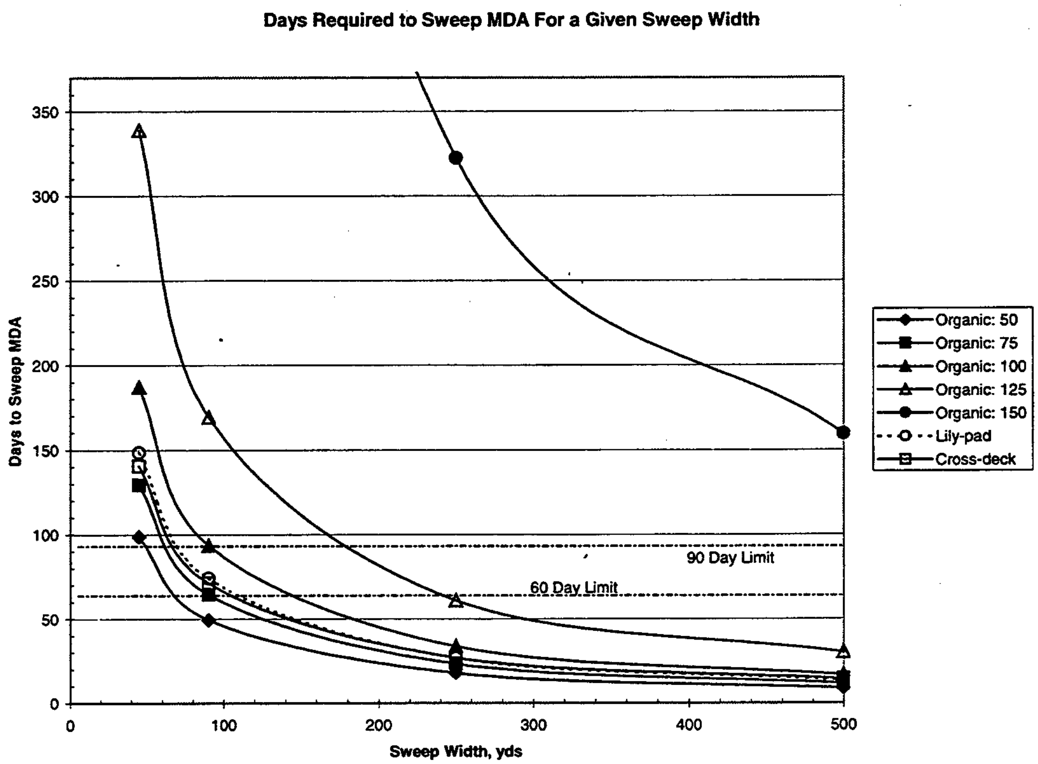


**Figure 10: 4-Organic, 2-Other Helicopters Available.**

With two helicopters available for lily-pad or cross-deck operations, the MDA can be swept in less than 90 days as long as the effective sweep width can be kept close to 90

yards. Organic operations must still be conducted within approximately 75 nm or less of the MDA to sweep the MDA within the 90-day limit.

Table 16 demonstrates the number of days required to sweep the large MDA by either 3 organic helicopters or 1 lily-pad or cross-deck helicopter. The results for the lily-pad and cross-deck helicopters will be the values as those found in Table 5. The important change for this iteration is to note the increased time-to-sweep values using organic helicopters.

| Transit Distance, nm | sw:45 | sw:90 | sw:250 | sw:500 |
|---|---|---|---|---|
| 50 | 131.7 | 65.8 | 23.7 | 11.7 |
| 75 | 172.4 | 86.2 | 31 | 15.3 |
| 100 | 249.5 | 124.8 | 44.9 | 22.2 |
| 125 | 451.9 | 225.9 | 81.3 | 40.2 |
| 150 | 2388.4 | 1194.2 | 429.9 | 212.6 |
| Lily-pad: 15 | 296.8 | 148.4 | 53.4 | 26.4 |
| Cross-deck: 5 | 279.1 | 140.6 | 51.9 | 26.7 |

**Table 16. 3-Organic, 1-Other Helicopter Available.**

Figure 11 provides a graphic interpretation of the data in Table 16. It shows that if the operational commander can only commit 3 helicopters to organic AMCM operations or only has one small-deck combatant available, the mother ship will have to remain in close proximity, (50 nm) of the MDA. Even with the mother ship at a distance of 50 nm, the number of days required to sweep the MDA is highly dependent on the effective sweep width. This situation presents a difficult decision for the operational commander, the number of days required to sweep the MDA could vary between 66 and 132 days, depending on the variability of sweep width.

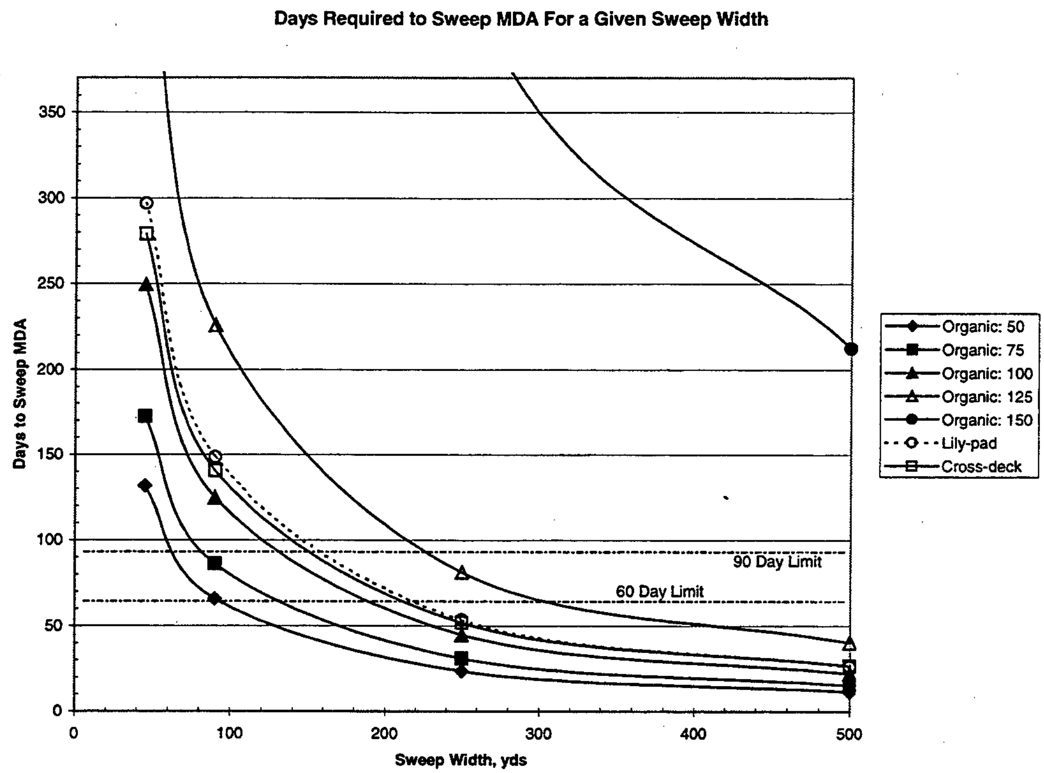


**Figure 11: 3-Organic, 1-Other Helicopter Available.**

Table 17 and Figure 12 present a possible solution to reducing the number of days required for SWIMS to sweep this large MDA. The benefit of an additional small-deck combatant for lily-pad or cross-deck becomes apparent. Table 8 shows that the sweeping capability of 2 lily-pad or 2 cross-deck helicopters come very close to the capability of 3 organic helicopters.

| Transit Distance, nm | sw:45 | sw:90 | sw:250 | Sw:500 |
|---|---|---|---|---|
| 50 | 131.7 | 65.8 | 23.7 | 11.7 |
| 75 | 172.4 | 86.2 | 31 | 15.3 |
| 100 | 249.5 | 124.8 | 44.9 | 22.2 |
| 125 | 451.9 | 225.9 | 81.3 | 40.2 |
| 150 | 2388.4 | 1194.2 | 429.9 | 212.6 |
| Lily-pad: 15 | 148.4 | 74.2 | 26.7 | 13.2 |
| Cross-deck: 5 | 140.6 | 71.3 | 26.9 | 14.3 |

**Table 17. 3-Organic, 2-Other Helicopters Available.**

Figure 12 shows how 2 "other" assets provide a better capability than the organic method at 75 nm, but require approximately one week more than the organic method at 50 nm. With two small-deck combatants available for SWIMS deployment, the operational commander can keep the mother ship farther from the MDA than would be required for "organic operations. This would make the "high-value" mother ship less vulnerable to attack and easier to defend.

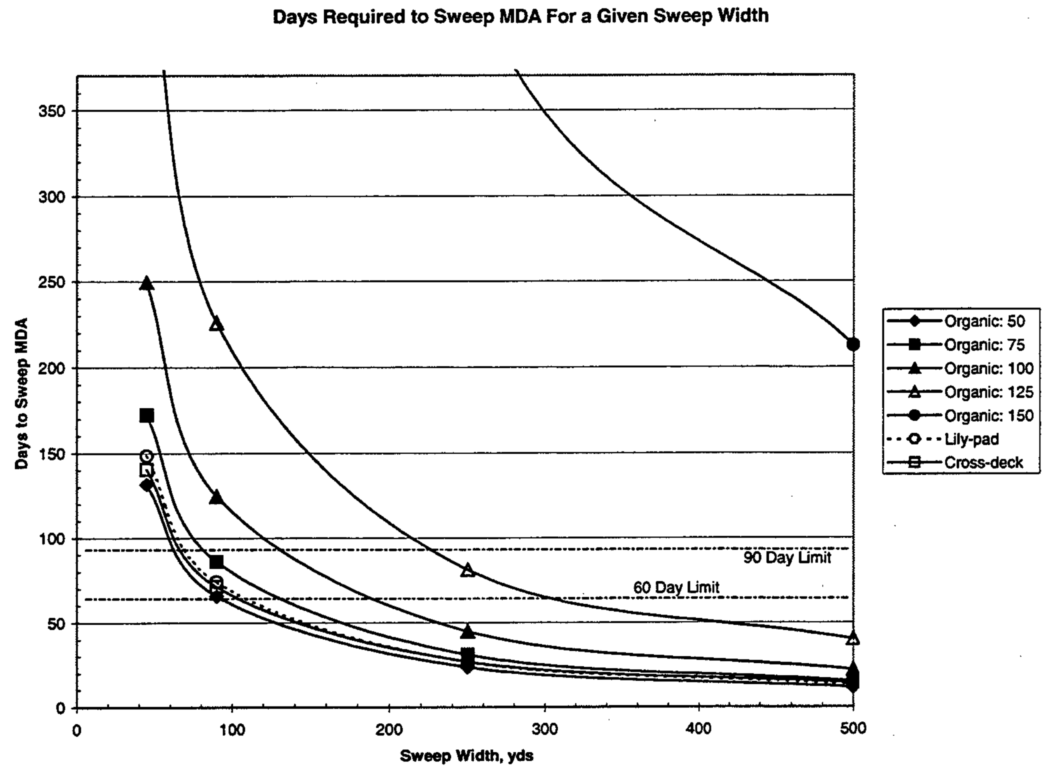


**Figure 12: 3-Organic, 2-Other Helicopters Available.**

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## APPENDIX D. DETAILED EXPLORATION OF DATA SET 2

Table 18 gives the results of 4 organic helicopters versus 1 lily-pad or cross-deck helicopter for sweep the single-short channel and Figure 13 provides a graphical interpretation of the data in Table 18. Figure 13 demonstrates that even with only one helicopter available for lily-pad or cross-deck operations, the short-length, single lane MDA can be cleared within 90 days. Additionally, as long as the sweep width can be kept close to 90 yards, a single helicopter can sweep the MDA in 60 days or less. This is of great benefit to the operational commander as this allows successful completion of the AMCM mission by means most suited to the tactical environment. If the mother ship is easily defendable in this case, the transit distance can be reduced to 75 or 50 nm. Reduced transit distances coupled with multiple sweep assets allow the number of days required to sweep to drop below 30 days. This would not allow much time for mine field re-seeding, or preparations to hold off amphibious forces. The short, single lane MDA would appear to be the ideal situation for AMCM forces to be presented with as it affords the widest range of tactical solutions.

| Transit Distance | Sw:45 | sw:90 | sw:250 | sw:500 |
|---|---|---|---|---|
| 50 | 24.02 | 12.01 | 4.32 | 2.14 |
| 75 | 31.44 | 15.72 | 5.66 | 2.8 |
| 100 | 45.52 | 22.76 | 8.19 | 4.05 |
| 125 | 82.43 | 41.22 | 14.84 | 7.34 |
| 150 | 435.71 | 217.86 | 78.43 | 38.79 |
| Lily-pad: 15 | 72.2 | 36.1 | 13 | 6.4 |
| Cross-deck: 5 | 69.4 | 35.7 | 14.1 | 8 |

**Table 18. Single Channel, 4-Organic, 1-Other Helicopter.**

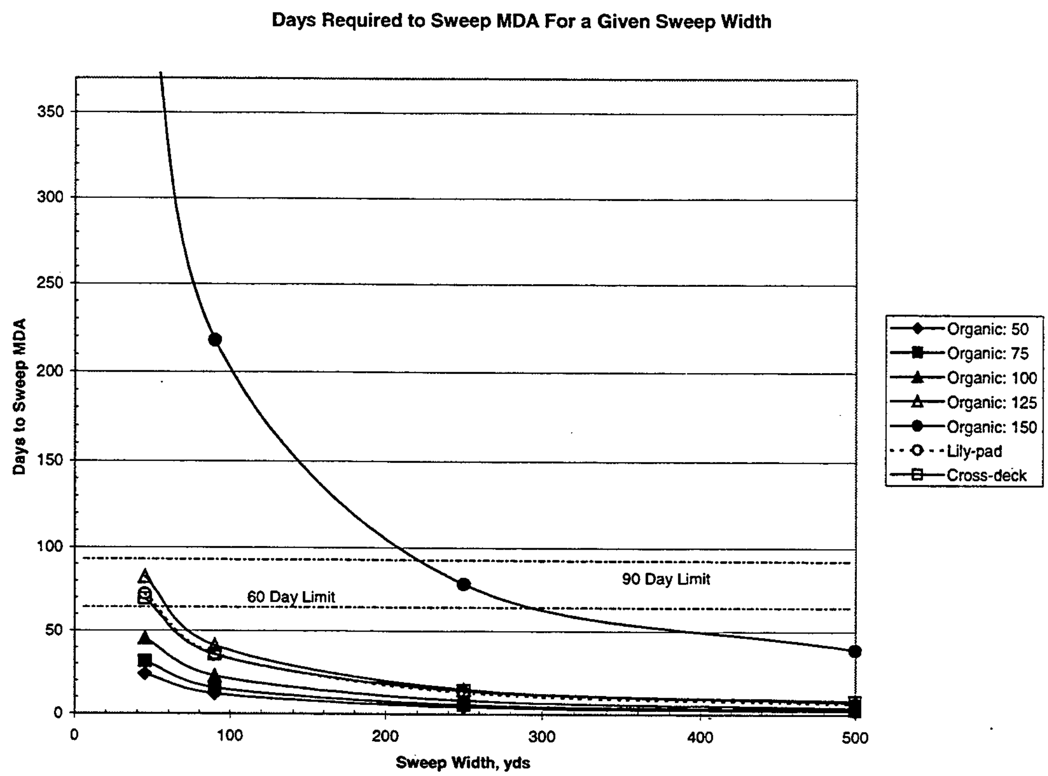


**Figure 13: Single Lane, 4-Organic, 1-Other Helicopter.**

Table 19 provides the results of having to sweep an additional channel along with the short channel. The total length of channel to be swept is slightly over half as long as the large MDA, (105 nm versus 180.2 nm), where the single short channel is 45 nm in length. This increase in swept channel length is sufficient to present the operational commander with a difficult AMCM force deployment decision.

| Transit Distance, nm | sw:45 | sw:90 | sw:250 | sw:500 |
|---|---|---|---|---|
| 50 | 56 | 28 | 10.1 | 5 |
| 75 | 73.4 | 36.7 | 13.2 | 6.5 |
| 100 | 106.2 | 53.1 | 19.1 | 9.5 |
| 125 | 192.3 | 96.2 | 34.6 | 17.1 |
| 150 | 1016.7 | 508.3 | 183 | 90.5 |
| Lily-pad: 15 | 168.4 | 84.2 | 30.3 | 15 |
| Cross-deck: 5 | 159.3 | 80.6 | 30.3 | 16 |

**Table 19. Dual Lane, 4-Organic, 1-Other Helicopter.**

Figure 14 gives the user a graphical representation of the data in Table 19. Comparing Figure 13 with Figure 14 demonstrate how the requirement of an additional objective could make the AMCM mission infeasible if assets and days available were limited.

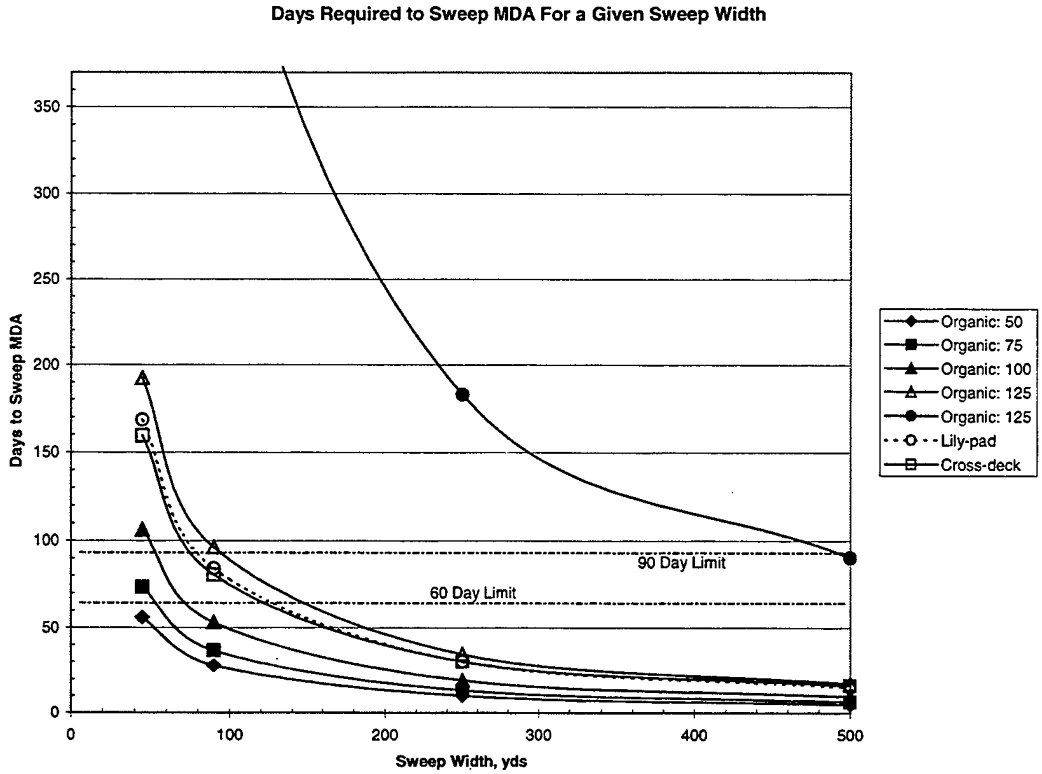


**Figure 14: Dual Lane, 4-Organic, 1-Other Helicopter.**

If the operational commander is required to sweep the MDA for two objectives, the mother ship must be moved into at least 100 nm for organic AMCM operations. The choice of using only one helicopter for lily-pad or cross-deck AMCM operations in this situation is only slightly better than 4-Helicopter organic operations. The single helicopter AMCM operations can only be completed within 90 days if the effective sweep width can be kept at the 90-yard level.

Table 20 represents the results of an additional helicopter for use in lily-pad or cross-deck AMCM operations.

| Transit Distance, nm | sw:45 | sw:90 | sw:250 | sw:500 |
|---|---|---|---|---|
| 50 | 24.0 | 12.0 | 4.3 | 2.1 |
| 75 | 31.4 | 15.7 | 5.7 | 2.8 |
| 100 | 45.5 | 22.8 | 8.2 | 4.1 |
| 125 | 82.4 | 41.2 | 14.8 | 7.3 |
| 150 | 435.7 | 217.9 | 78.4 | 38.8 |
| Lily-pad: 15 | 36.1 | 18.0 | 6.5 | 3.2 |
| Cross-deck: 5 | 35.7 | 18.9 | 8.1 | 5.0 |

**Table 20. Single Lane, 4-Organic, 2-Other Helicopters.**

Figure 15 provides a graphic representation of Table 20 and shows that an additional small-deck based AMCM asset serves to further reduce the number of days required to sweep the single-lane short channel MDA.

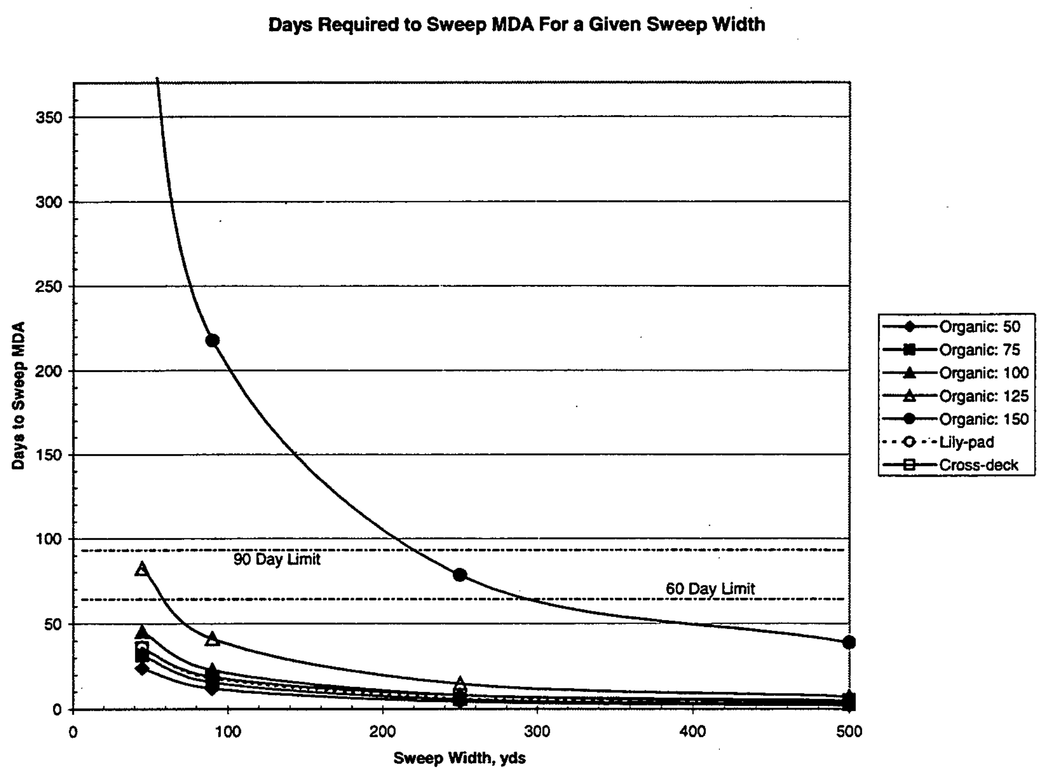


**Figure 15: Single Lane, 4-Organic, 2-Other Helicopters.**

Figure 15 demonstrates that with the additional small-deck asset, the MDA can be swept in approximately one month, depending on effective sweep width. Only two helicopters would be required for AMCM operations and the large-deck combatant can maintain a safe standoff distance. By adding a new tactical objective, the reliance on small-deck AMCM operations starts to present itself once more. .

Table 21 represents the data for 4 organic helicopters sweeping the dual channel scenario versus 2 lily-pad or cross-deck helicopters.

| Transit Distance, nm | sw:45 | sw:90 | sw:250 | sw:500 |
|---|---|---|---|---|
| 50 | 56.0 | 28.0 | 10.1 | 5.0 |
| 75 | 73.4 | 36.7 | 13.2 | 6.5 |
| 100 | 106.2 | 53.1 | 19.1 | 9.5 |
| 125 | 192.3 | 96.2 | 34.6 | 17.1 |
| 150 | 1016.7 | 508.3 | 183 | 90.5 |
| Lily-pad: 15 | 84.2 | 42.1 | 15.2 | 7.5 |
| Cross-deck: 5 | 80.6 | 41.3 | 16.2 | 9.0 |

**Table 21. Dual Lane, 4-Organic, 2-Other Helicopters.**

Figure 16 provides a graphic example of the data results from Table 21. Figure 16 demonstrates the benefit of additional small-deck assets and how said benefit increases as the overall length of the channel(s) to be swept increases. This benefit relates directly to decrease effective sweep times and also provides multiple employment decisions for the operational commander.

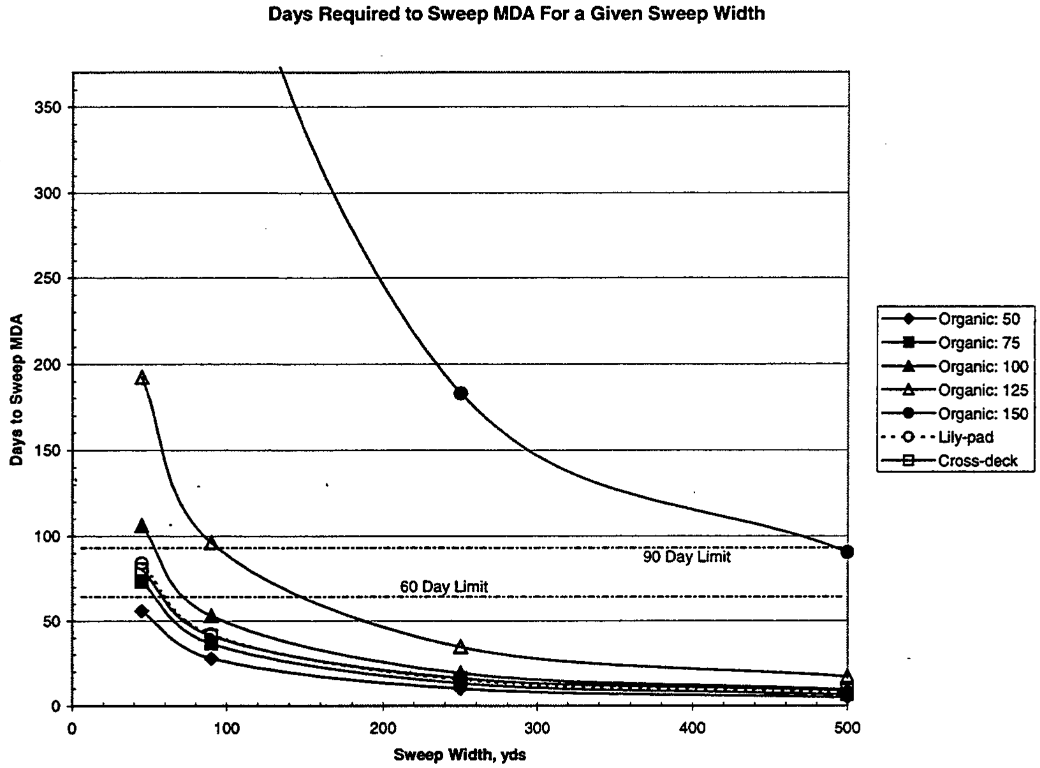


**Figure 16: Dual Lane, 4-Organic, 2-Other Helicopters.**

Figure 16 shows that 2 helicopters sweeping the dual channel scenario compares favorably with organic AMCM operations with a transit distance as close as 75 nm. As the data set exploration continues by comparing 3 organic helicopters deployed against 1 or 2 "other" helicopters, being able to employ two small-deck combatants will have an even greater advantage.

Table 22 presents the results of comparing 3 organic assets against 1 "other" asset for sweeping the single, short channel and Figure 17 provides shows the results from Table 22 graphically.

| Transit Distance, nm | sw:45 | sw:90 | sw:250 | sw:500 |
|---|---|---|---|---|
| 50 | 32.0 | 16.0 | 5.8 | 2.9 |
| 75 | 41.9 | 21.0 | 7.5 | 3.7 |
| 100 | 60.7 | 30.3 | 10.9 | 5.4 |
| 125 | 110.0 | 55.0 | 19.8 | 9.8 |
| 150 | 581.0 | 290.5 | 104.6 | 51.7 |
| Lily-pad: 15 | 72.2 | 36.1 | 13.0 | 6.4 |
| Cross-deck: 5 | 69.4 | 35.7 | 14.1 | 8.0 |

**Table 22. Single Lane, 3-Organic, 1-Other Helicopter.**

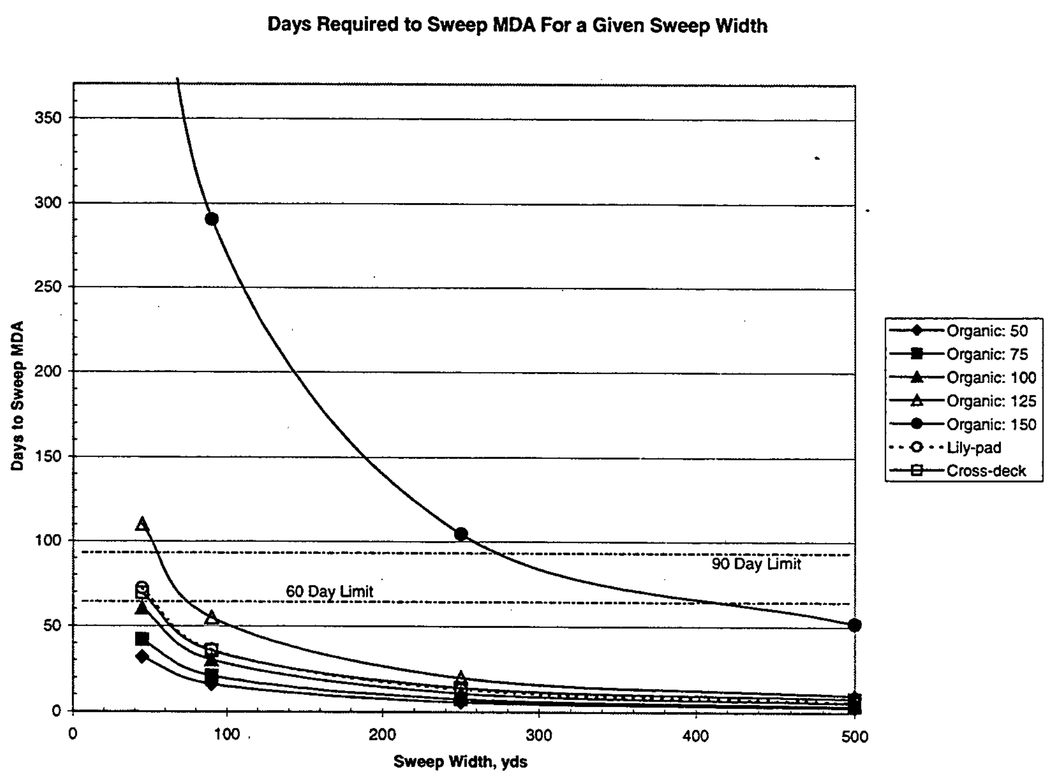


**Figure 17: Single Lane, 3-Organic, 1-Other Helicopter.**

With only 3 organic assets available, the single, small-deck asset comes close to being able to sweep the area in the same number of days as three organic helicopters operating at a transit distance of 100 nm.

Table 23 represents the data set with two lanes to sweep and 3 organic helicopters or 1 "other" helicopter available and Figure 18 provides a graphic representation of the data.

| Transit Distance, nm | sw:45 | sw:90 | sw:250 | sw:500 |
|---|---|---|---|---|
| 50 | 74.7 | 37.6 | 13.4 | 6.7 |
| 75 | 97.8 | 48.9 | 17.6 | 8.7 |
| 100 | 141.6 | 70.8 | 25.5 | 12.6 |
| 125 | 256.5 | 128.2 | 46.2 | 22.8 |
| 150 | 1355.6 | 677.8 | 244 | 120.7 |
| Lily-pad: 15 | 168.4 | 84.2 | 30.3 | 15 |
| Cross-deck: 5 | 159.3 | 80.6 | 30.3 | 16 |

**Table 23. Dual Lane, 3-Organic, 1-Other Helicopter**

Days Required to Sweep MDA For a Given Sweep Width

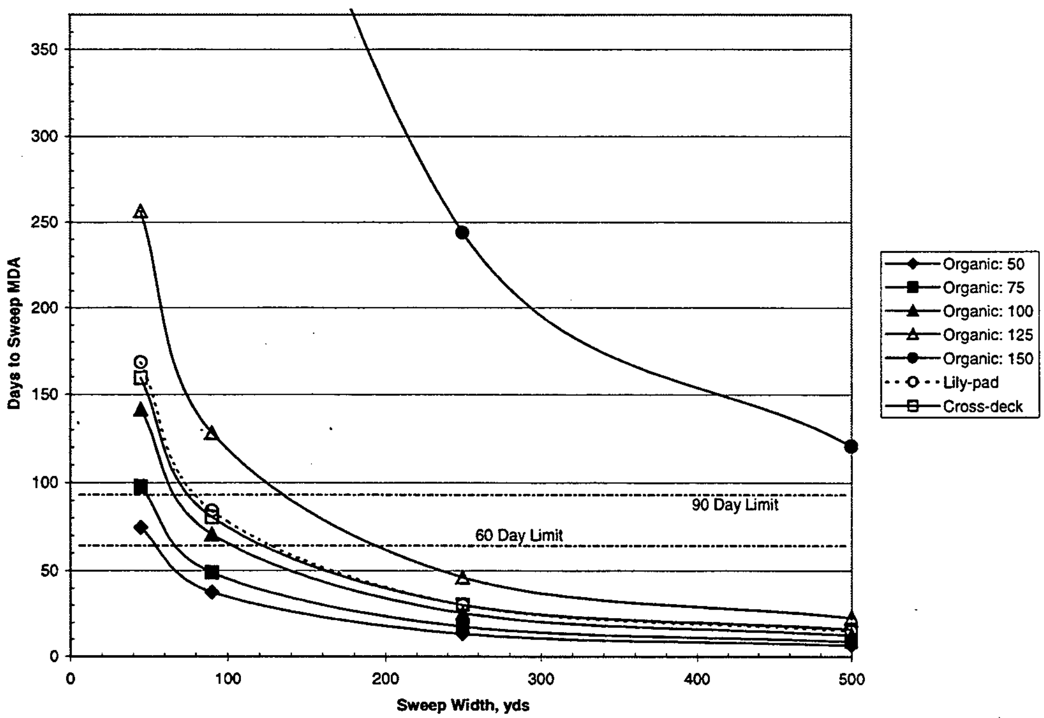


**Figure 18: Dual Lane, 3-Organic, 1-Other Helicopter**

Figure 18 demonstrates the difficulty in successfully sweeping an MDA with a significant overall channel length. The only methods that can complete the task for the designated attributes are high effective sweep width values associated with 50 nm and 75 nm transit distances. This is a difficult problem for the operational commander. If safety of the mother ship is of primary concern, then a time-to-sweep of at least 80 days must be accepted.

Table 24 shows the results of comparing 3 organic helicopters against 1 lily-pad or cross-deck helicopter for AMCM operations involved with the single, short-channel MDA.

| Transit Distance, nm | sw:45 | sw:90 | sw:250 | sw:500 |
|---|---|---|---|---|
| 50 | 32.0 | 16.0 | 5.8 | 2.9 |
| 75 | 41.9 | 21.0 | 7.5 | 3.7 |
| 100 | 60.7 | 30.3 | 10.9 | 5.4 |
| 125 | 110.0 | 55.0 | 19.8 | 9.8 |
| 150 | 581.0 | 290.5 | 104.6 | 51.7 |
| Lily-pad: 15 | 36.1 | 18.0 | 6.5 | 3.2 |
| Cross-deck: 5 | 35.7 | 18.9 | 8.1 | 5.0 |

**Table 24. Single Lane, 3-Organic, 2-Other Helicopters.**

Figure 19 provides a graphic representation of the data in Table 24. Here again, the operational commander is presented with several deployment methods that should successfully complete the sweeping operation in less than 60 days.

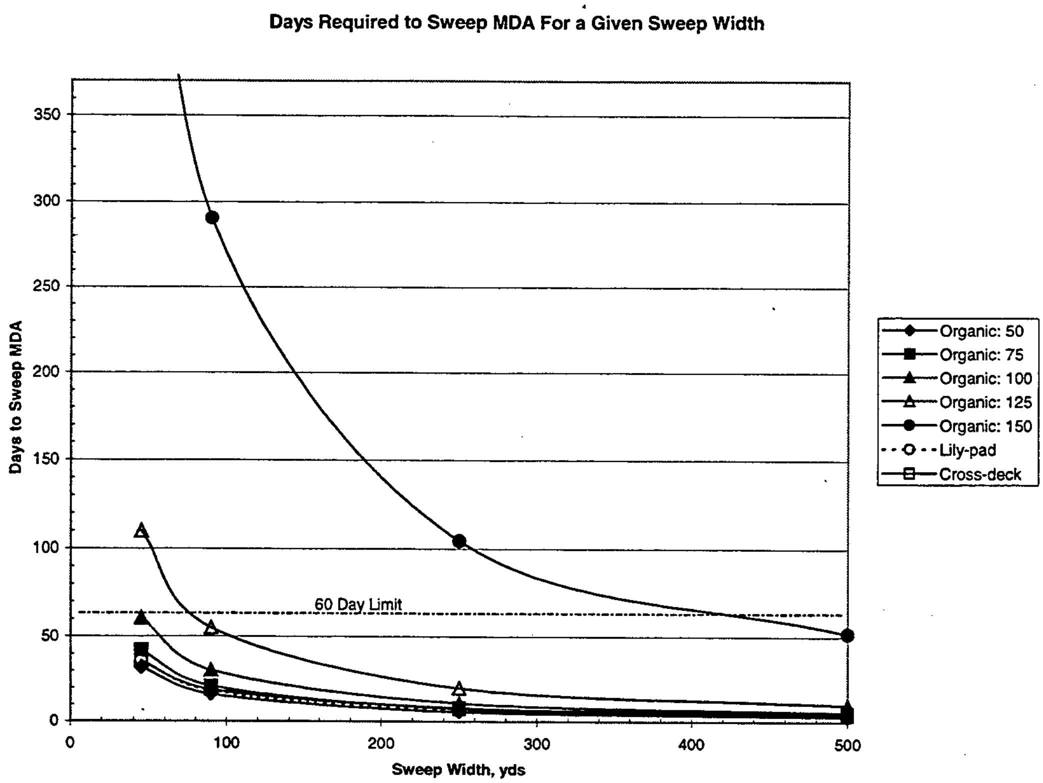


**Figure 19: Single Lane, 3-Organic, 2-Other Helicopters.**

Comparing the results of Figure 19 with those of the 4 organic model in Figure 15 shows that if organic sweeping is preferred, 3 helicopters could perform the task within 60 days from a transit distance of 100 nm or less. If small-deck operations are preferred, the task can be completed in approximately 40 days or less.

Table 25 provides the results of sweeping both channels with either 3 organic AMCM helicopters or 2 small-deck AMCM helicopters and Figure 20 provides a graphic representation of the data. The effects of the greater channel length can be seen as an increase in the time-to-sweep values for all methods.

| Transit Distance, nm | sw:45 | sw:90 | sw:250 | sw:500 |
|---|---|---|---|---|
| 50 | 74.7 | 37.6 | 13.4 | 6.7 |
| 75 | 97.8 | 48.9 | 17.6 | 8.7 |
| 100 | 141.6 | 70.8 | 25.5 | 12.6 |
| 125 | 256.5 | 128.2 | 46.2 | 22.8 |
| 150 | 1355.6 | 677.8 | 244.0 | 120.7 |
| Lily-pad: 15 | 84.2 | 42.1 | 15.2 | 7.5 |
| Cross-deck: 5 | 80.6 | 41.3 | 16.2 | 9.0 |

**Table 25. Dual Lane, 3-Organic, 2-Other Helicopters.**

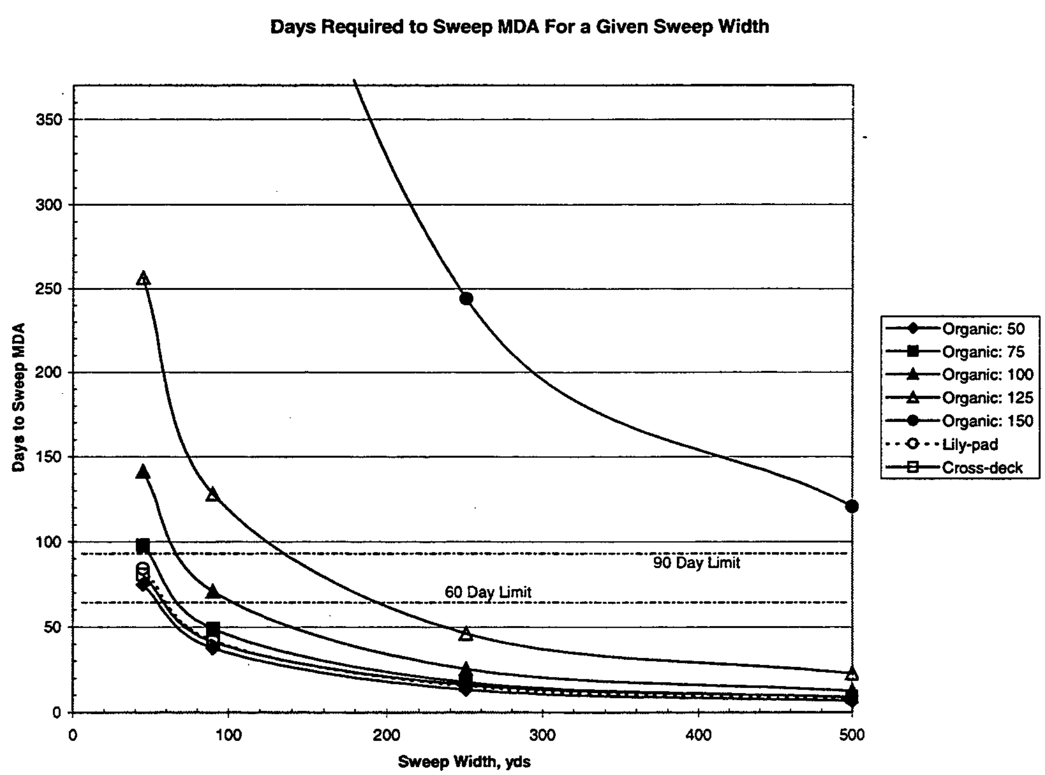


**Figure 20: Dual Lane, 3-Organic, 2-Other Helicopters.**

Figure 20 shows that in order to successfully sweep the two-channel area within the 60 day limit, the effective sweep width must be kept as close 90 yards as possible. The possible courses of action then become: organic operations at a transit distance of 75 nm or less or, AMCM operations from two small-deck combatants.

# APPENDIX E. SAMPLE CALCULATIONS FOR NUMBER OF HELICOPTERS REQUIRED MODEL

Table 26 displays the results of the sample calculation for the number of helicopters required to sweep a given area in specified number of days.

| INPUT | | OUTPUT | |
|---|---|---|---|
| channel_w, (nm) | 0.50 | #_sections | 37 |
| area_len, (nm) | 180.20 | eff_sweep, (yds) | 90.00 |
| section_len, (nm) | 5.00 | mcm_eff | 1.9179 |
| ship_count | 10 | clear | 0.8531 |
| sweep_vel, (kts) | 22 | turns | 12 |
| depth | 1 | sweep_prob | 1 |
| nav_error, (yds) | 25 | track_sep, (yds) | 90.0000 |
| time_to_turn, (min) | 3.0 | eff_miss_time, (hrs) | 0.1061 |
| mcm_density | 1 | Etotitl_sec, (hrs) | 30.8081 |
| swp_days_avail, (days) | 60 | Etotitl, (hrs) | 1139.8990 |
| trans_dist, (nm) | 150.0 | helo_miss_per_day | 3 |
| trans_vel, (kts) | 110 | num_missions_req | 10747.6190 |
| refuel_time, (min) | 12.0 | miss_req_per_day | 179 |
| stream_time, (min) | 15.0 | num_helos_req | 60 |
| t_around_time, (min) | 10.0 | | |
| mission_time, (hrs) | 3.5 | | |
| day_time, (hrs) | 12.0 | | |
| log_xfer_days, (days) | 0 | | |

**Table 26. Results From Number Of Helicopters Required Calculation.**

Using the data from Table 26, and the equations above, the following provides a numerical example for calculating the number of helicopters required to sweep a given MDA in a prescribed number of days. This variation of the model was created in the same manner as the original model, using Microsoft Excel '97.

Equation 13 ...

day_time, (hr) = 12.0, mission_time, (hr) = 3.5,

refuel_time, (min) = 12.0,

$$\text{helo\_miss\_per\_day} = \left\lfloor \frac{12.0}{3.5 + \left(12.0 * \left(\frac{1}{60}\right)\right)} \right\rfloor = 3\,. \tag{13}$$

Equation 14 ...

num_miss_req = 10747.62, sweep_days_avail, (days) = 60,

$$\text{miss\_req\_per\_day} = \frac{10747.62}{60} = 179.127\,. \tag{14}$$

Equation 15 ...

miss_req_per_day = 179.127, helo_miss_per_day = 3,

$$\text{num\_helo\_req} = \frac{179.127}{3} = \lceil 59.67 \rceil = 60\,. \tag{15}$$

For comparison, Table 27 displays the number of helicopters required to sweep the same MDA with having moved the transit distance into 75 nm from 150 nm. Comparing these results with the results in Table 4 and Figure 5 can provide the operational commander with a different and possibly valuable view of similar tactical situations.

| INPUT | | OUTPUT | |
|---|---|---|---|
| channel_w, (nm) | 0.50 | #_sections | 37 |
| area_len, (nm) | 180.20 | eff_sweep, (yds) | 90.00 |
| section_len, (nm) | 5.00 | mcm_eff | 1.9179 |
| ship_count | 10 | clear | 0.8531 |
| sweep_vel, (kts) | 22 | turns | 12 |
| depth | 1 | sweep_prob | 1 |
| nav_error, (yds) | 25 | track_sep, (yds) | 90.0000 |
| time_to_turn, (min) | 3.0 | eff_miss_time, (hrs) | 1.4697 |
| mcm_density | 1 | Etotitl_sec, (hrs) | 30.8081 |
| swp_days_avail, (days) | 60 | Etotitl, (hrs) | 1139.8990 |
| trans_dist, (nm) | 75.0 | helo_miss_per_day | 3 |
| trans_vel, (kts) | 110 | num_missions_req | 775.6014 |
| refuel_time, (min) | 12.0 | miss_req_per_day | 12 |
| stream_time, (min) | 15.0 | num_helos_req | 4 |
| t_around_time, (min) | 10.0 | | |
| mission_time, (hrs) | 3.5 | | |
| day_time, (hrs) | 12.0 | | |
| log_xfer_days, (days) | 0 | | |

**Table 27. Number Of Helicopters Required, 75 nm Transit.**

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